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SYSTEM AVIONIC ARCHITECTURES FOR RPVS.(U)

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SYSTEM AVIONIC ARCHITECTURES FOR RPVs

TEXAS INSTRUMENTS INCORPORATED
EQUIPMENT GROUP
13500 NORTH CENTRAL EXPRESSWAY
DALLAS, TEXAS 75222

APRIL 1977

FINAL REPORT FOR PERIOD FEBRUARY 1976 - AUGUST 1976

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AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

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APPROVAL STATEMENT

This final report was submitted by Texas Instruments Incorporated under Contract F33615-76-C-1215, Project 2003, Task 01, Work Unit 08 for the U.S. Air Force Avionics Laboratory, Wright-Patterson AFB, Ohio 45433. 2Lt Richard S. Butler was the Project Engineer. This report has been reviewed by the Information Office (IO) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

The reader is advised that the basic purpose of this study effort was to explore the merits of various system avionic digital architectures having possible applicability to Advanced Remotely Piloted Vehicles. For purposes of this early investigation, the contractor was permitted to analyze and synthesize various architectures relative to the use of Texas Instruments computers, in that the scope of this effort did not permit consideration of the many types/classes of computers currently available. Therefore, contractor reference to a specific Texas Instruments product should not necessarily be construed as reflecting Air Force endorsement. More in-depth architectural studies, currently underway by the sponsoring agency of this effort, will be required to draw more definitive conclusions.

This technical report has been reviewed and approved for publication to permit the stimulation and exchange of ideas.

Richard S. Butler

RICHARD S. BUTLER, 2LT, USAF
Project Engineer

David R. Morgan

DAVID R. MORGAN, Technical Manager
System Design Group
Avionics Synthesis & Analysis Branch
System Avionics Division

FOR THE COMMANDER

James D. Everett

JAMES D. EVERETT, Colonel, USAF
Chief, System Avionics Division
Air Force Avionics Laboratory

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Results are presented from a 6-month study to design an avionic digital processing system for the multi-mission Advanced Remotely Piloted Vehicle (ARPV) application. The recommended approach is a microprocessor-based design consisting of a distributed processing network with modular processor/memory elements (PEs) interconnected via a MIL-STD-1553A data bus. The objective was to design a digital processing system providing not only adequate performance for the anticipated ARPV missions but also the lowest possible life cycle cost (LCC). Three different processing systems were designed to meet performance requirements for specific postulated ARPV missions. The total LCC for each candidate system was then estimated using a postulated 10-year life-cycle scenario. The "optimum" design

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was selected on the basis of minimum LCC. In addition to the minimum LCC, the recommended system also provides the best performance in terms of flight-critical reliability.

The extensive use of standard modules throughout the distributed network provides flexible system performance by allowing throughput capacity and/or memory capacity to be increased readily as processing requirements demand. The use of standard modules is also important in achieving a low LCC. Results from this study, in particular the modular design of the basic PE, are applicable not only to the ARPV problem but other Air Force avionic processing applications as well.

PREFACE

This final report presents the results of work performed on Air Force Contract F33615-76-C-1215, Project No. 2003, Task No. 01 (System Avionic Architectures for RPVs) for the Air Force Avionics Laboratory. The Air Force Program monitor was 2dLt. R.S. Butler, AFAL/AAA.

The research effort was conducted by Texas Instruments Incorporated, Dallas, Texas from 2 February 1976 to 2 August 1976. The final report was submitted in February 1977. Principal contributors to this report were R. Allen, L. Chamberlin, J. Early, J. Graham, W. Grimes, E. Karintis, A. Minnick and T. Shipchandler.

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SECTION I

INTRODUCTION

This report describes results of a 6-month study to design an avionic digital processing system for the multimission Advanced Remotely Piloted Vehicle (ARPV) application. The objective was to achieve a digital processing system providing not only adequate performance for anticipated ARPV missions but also the lowest possible life-cycle cost (LCC). Three different processing systems were designed to meet performance requirements for specific postulated ARPV missions. The total LCC for each candidate system was then estimated using a postulated 10-year life-cycle scenario. The recommended approach, selected on the basis of minimum LCC, is a microprocessor-based design consisting of a distributed processing network with modular processor/memory elements (PEs) interconnected by a serial data bus.

The scope of the program was limited to system architectures utilizing a single command/response time-division multiplex data bus meeting the requirements of MIL-STD-1553A. Within this scope, the general approach was to design and analyze several different systems representing the most promising avionic processing concepts prevalent today. Most of the effort was directed toward investigating two variations of a microprocessor-based distributed processing concept in which separate homogeneous processing elements are interconnected by a MIL-STD-1553A data bus. In order to provide a common reference for performance and LCC comparisons, a conventional minicomputer-based federated processing concept was also included as part of this study. In the federated concept, a single central computer is connected by a MIL-STD-1553A data bus to a number of remote terminals.

As shown in Table 1, the three processing systems designed in this study are designated as: the Centralized system, the DP/M (Distributed Processor/Memory) system, and the Hybrid system. The degree of segmentation or partitioning of the total ARPV processing problem is the principal characteristic which differentiates these three systems. For the Centralized system, the processing problem is not partitioned and all processing tasks are accomplished in one computer. In the DP/M system, the problem is partitioned by task with each major processing task assigned to an individual PE. In the Hybrid system, which is the approach recommended by this study, the processing problem is partitioned by functional area with groups of related processing tasks assigned to individual PEs.

The best utilization of microprocessors or microprocessor chip sets in the ARPV application was an important consideration in this study. Current proliferation of microprocessors and related components compounds the already complex and multifaceted problem of designing an avionic processing system. In order to achieve minimum LCC, design of the distributed processing systems was based on homogeneous PEs formed with standard building-block modules. The use of standard modules plays an important role in achieving minimum LCC both in terms of reduced initial acquisition costs and reduced sustaining costs. Standard modules also provide flexible system performance by allowing throughput capacity and/or memory capacity to be increased readily as processing requirements demand. This kind of basic system flexibility is expected to be particularly important as the avionic processing requirements change over the life of the ARPV.

TABLE 1. CHARACTERISTICS OF CANDIDATE PROCESSING SYSTEMS

System Parameter	Processing System Centralized	DP/M	Hybrid
Weight* (pounds)	143	246	187
Power* (watts)	753	515	357
Volume* (in^3)	5150	6700	4690
Number of PEs or Remote Terminals*	11	17	11
Peak Throughput Utilization* (percent)	72	16	25
Peak Memory Utilization* (percent)	78	59	65
Total System MTBF at 45°C* (hours)	1001	729	962
Mission Critical MTBF at 45°C (hours)	1104	928	1084
Flight Critical MTBF at 45°C (hours)	1485	1586	1874
Unit Cost for 550 System Buy*	$105,000	$89,500	$63,500
Relative LCC	1.47	1.28	1.0

*Each processing system configured for strike mission

The standard PE or microcomputer used in the DP/M system and in the recommended Hybrid system is based on an existing commercially available I^2L 16-bit microprocessor chip (Texas Instruments SBP 9900). The microprocessor chip plus 1,536 words of nonvolatile programmable read-only memory (PROM) and 1,024 words of read/write random-access memory (RAM) form a microprocessor module (one printed wiring board) which is the basic building block for the standard PE. This standard PE is used throughout the distributed processing networks with standard input/output modules and standard memory modules added as required for a particular processing task or function. This standard module concept is applicable not only to the ARPV problem but other Air Force avionic processing problems as well. The use of a standard set of modules across a wide range of Air Force and other military applications could have a significant impact in terms of reducing total life-cycle cost for all the applications.

Each of the three candidate processing systems listed in Table 1 was designed to satisfy representative ARPV processing requirements which were defined as part of this study. The initial step in defining processing requirements was postulating scenarios for a strike, a reconnaissance (recce), and an electronic warfare (EW) mission (Appendix A). From the mission scenarios, a list of required mission functions and generic equipment types was determined (Appendix B). Mission algorithms were then defined in terms of estimated throughput, memory, and data input/output requirements (Appendix C).

In addition to meeting the actual processing requirements, the candidate processing systems also were designed to meet mission reconfiguration requirements of the multimission ARPV. In each of the systems, reconfiguration of processing resources is facilitated by separating the processing requirements into core (required for all missions) and mission-specific categories. For the DP/M and Hybrid systems, mission reconfiguration is accomplished by removing unnecessary PEs for the bus network, adding required PEs and programming the mission-specific part of the system. For the Centralized system, reconfiguration is accomplished by removing unnecessary remote terminals from the bus, adding required terminals and reprogramming the mission-specific part of the central computer.

As part of an iterative design cycle, the performance of each candidate system was analyzed using a System Network Simulator (SNS). The purpose of this analysis was to determine loading on the MIL-STD-1553A bus used in each case. SNS results for peak bus traffic during the strike mission (segment No. 8) are summarized in Table 2. For all system configurations, worst case loading of the bus was found to be approximately 10 percent or less of the bus capacity (1 megabit/second).

TABLE 2. MIL-STD-1553A BUS TRAFFIC SUMMARY

System	Peak Data Rate (kilobits per second)	Peak Bus Utilization (percent)	MIL-STD-1553A Related Overhead (percent)
Centralized	39.7	3.97	37.4
DP/M	101.3	10.13	48.4
Hybrid	93.9	9.39	47.0

In interpreting the results shown in Table 2, it is important to note that there are a number of factors which lead to higher bus traffic for the distributed systems as compared to the Centralized system. For example, the distributed systems use the network bus for both transfer of detailed system management information and transfer of intertask data. In the Centralized system neither of these types of transactions appear on the bus. Another factor contributing to increased bus traffic is the lack of a broadcast mode in the MIL-STD-1553A protocol. This leads to repetitive messages for the distributed systems which are not required in the Centralized case. Table 2 also shows that bus traffic overhead (command and status words) is higher for the distributed systems. This is expected since the bulk of the data flow in the distributed networks is associated with terminal-to-terminal transfers requiring four overhead words per message according to MIL-STD-1553A protocol. The Centralized system on the other hand is characterized by terminal-to-controller and controller-to-terminal transfers which require only two overhead words per message. Details of the SNS computer runs are presented in Appendix D.

Also, as part of the design cycle, complete reliability and maintainability analyses were performed for each candidate system. Reliability factors (MTBF) were estimated for each configuration at assumed operating temperatures of 45° to 80°C. MTBF estimates for operation at 45°C are summarized in Table 1 for total-system, mission-critical, and flight-critical failures. In the important area of flight-critical failures, the distributed systems show improved reliability over the Centralized system. This is due to partitioning of the processing tasks and the natural hardware redundancy which occurs in the distributed network approach. Detailed results from the reliability and maintainability analyses are presented in Section III and Appendix E of this report.

After the required level of performance was verified for each system, total LCC was estimated. This estimate was made on the basis of a postulated ARPV life-cycle scenario consisting of a 10-year peacetime period followed by a 30-day conflict. The LCC estimates include software and hardware costs for both ground-support equipment and onboard ARPV processing equipment. The LCC model used in this study and a listing of input data for the model are presented in Appendix F and Appendix G, respectively. In addition to the conventional LCC categories of acquisition and sustaining costs, other factors were considered such as ARPV attrition due to processor system failure.

Using the particular life-cycle scenario defined in this study, system acquisition cost was found to be the dominant factor in total LCC for each of the three candidate systems. Estimated acquisition cost for each system is listed in Table 1. Acquisition costs for individual components in each system are documented in Section III. Because of necessary assumptions made in defining any example life-cycle scenario, the most meaningful interpretation of the LCC results is to compare systems on a relative basis. Therefore, relative LCC values are shown in Table 1. It should be noted that the DP/M and Hybrid LCC estimates generated in this study are for homogeneous processing systems. For nonhomogeneous systems, it is expected that LCC would be higher, primarily due to higher sustaining costs.

Accommodating future growth in ARPV processing requirements is an important factor in evaluating potential system configurations. The recommended Hybrid system is quite flexible in terms of future growth. Using the most demanding processing requirements defined in this study (strike mission), the Hybrid system is found to be 25 percent loaded in terms of available throughput and 65 percent loaded in terms of available memory. Clearly, there is ample margin for reasonable growth. If future requirements exceed the available growth margin, additional standard PEs can be added to the existing network to satisfy essentially any practical requirement.

Section II of this report contains a discussion of general tradeoff considerations regarding various approaches to the ARPV processing problem. Section III provides a detailed description of the three candidate processing systems. A life-cycle scenario is postulated and total cost of ownership estimated for each candidate system in Section IV. Section V contains a discussion of the study conclusions and recommendations for future work.

SECTION II

DISCUSSION OF THE ARPV PROCESSING PROBLEM

This section describes general system architectures for the ARPV processing application. General software development criteria to be used in the ARPV software system design are presented, including a discussion on the use of High-Order Language (HOL) versus Assembly Language (AL). The hardware considerations in implementing the ARPV processing system also are discussed.

The ARPV avionic processing system must satisfy a number of conflicting requirements. It must provide required multimission performance with minimum LCC. It must be reliable enough to ensure a high probability of mission and flight success. It also must provide for the future addition of sensors or equipment which may as yet be in the conceptual stages. The current state of computer-related technology ensures that required ARPV processing system performance can be achieved. The most difficult aspect of the problem is achieving a satisfactory level of performance with minimum LCC. Minimum LCC implies an optimum mix of numerous complex system parameters, including system maintenance requirements, support equipment costs, support personnel training costs, spares inventory requirements, recurring acquisition costs, and development costs.

A. PROCESSING SYSTEM ARCHITECTURES

Two basic processing system architectures are generally considered appropriate for the ARPV application: the federated system and the distributed system. Both architectures are compatible with the use of a standard data bus concept (MIL-STD-1553A) which is desirable for system flexibility and future growth.

1. The Federated System

A federated processing system (Figure 1) is defined as a computer system topology consisting of shared information transfer paths and one or more centrally located processors. Such a system is generally characterized by one or more high throughput computers connected through a common data bus to one or more remote terminals. The federated system, generally, does not provide for processing at a remote location. This architecture does provide a capability for growth and a limited degree of functional redundancy if multiple processors are utilized. In a federated system the processor or processors must have sufficient throughput to preprocess raw data from the remote terminals in addition to meeting the real time requirements of the primary avionics algorithms. The system software also is complicated by the general nature of the multitask environment.

2. The Distributed System

A distributed processing system (Figure 2) is defined as a multiprocessor configuration with shared information-transfer paths. The distributed system differs from the multiprocessor version of the federated system in that individual processors have dedicated resources (e.g., sensors) assigned which cannot communicate with the remainder of the system except through the

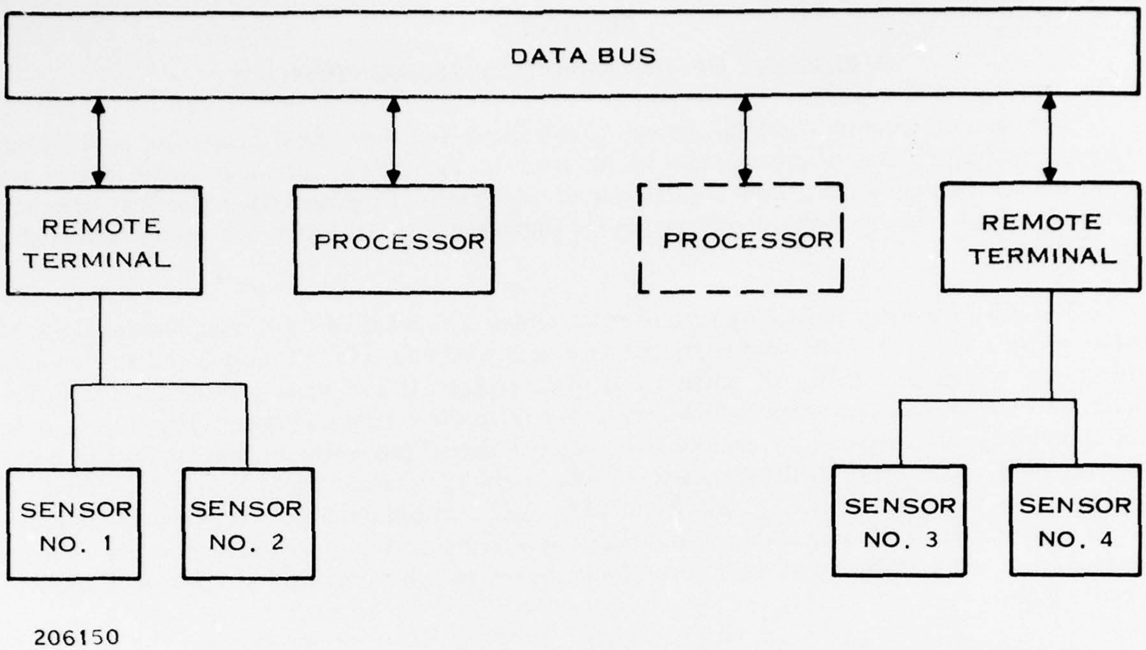

Figure 1. Federated Processing System

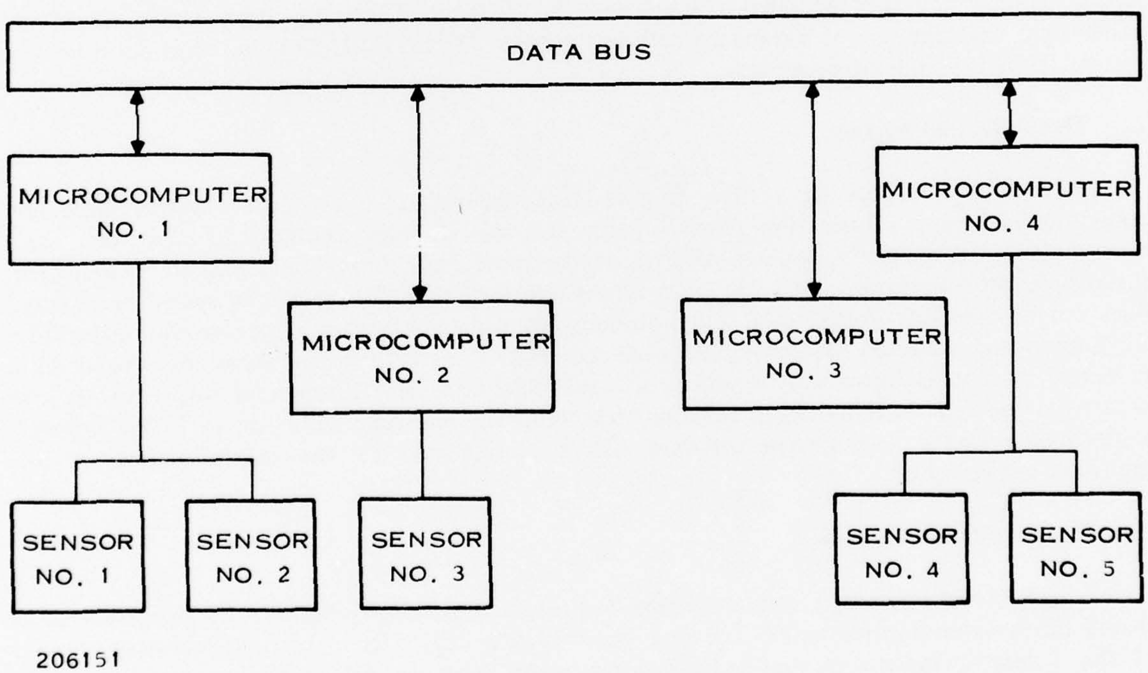

Figure 2. Distributed Processing System

processor itself. Although a number of variations are possible, distributed system architecture is generally characterized by several low-or medium-throughput computers which communicate over a common data bus. Modular microprocessor/memory elements are ideally suited for use in a distributed system. The DP/M and Hybrid configurations designed in this study are examples of distributed processing systems.

The distributed architecture lends itself to a modular approach in terms of both hardware and software. Consequently, it is an ideal design for those applications in which a relatively large problem can be partitioned into smaller tasks. Previous Air Force studies have shown that avionic processing applications generally conform to this requirement.[1,2] Partitioning criteria include optimal resource allocation, convenience, functional redundancy, reliability, data bus traffic, and cost considerations.

Partitioning of the avionic processing requirements and the need for reconfiguration of processing resources for different ARPV missions influences the nature of the distributed system software. Executive software for the distributed processing architecture can be table driven and thus relatively simple and flexible. A table-driven executive permits separation of executive logic and application logic modules. Not only can modifications and additions be made to application software modules, but the capabilities of the executive can be expanded by simple changes to standard table data.

It is generally accepted that modularity in a complex system can produce savings in a number of areas including development, production, and maintenance costs. The degree of modularity which can be achieved in a distributed system, therefore, can be an important factor in achieving a low LCC. Modularity also provides a high degree of flexibility in the distributed system in that a wide range of performance and redundancy levels can be easily achieved.

B. GENERAL SOFTWARE CONSIDERATIONS

1. System Oriented Software Development

Many large processing systems have been developed in an environment where the hardware is designed without careful consideration of possible software implications. The ARPV software system design should be accomplished with a design philosophy in which hardware and software issues are addressed simultaneously in a coordinated manner. The ARPV operational environment requires that the software be reliable and easily maintained. The potential high cost associated with software failure makes it imperative that the software explicitly meet functional and performance requirements. The certainty of changing ARPV missions and mission requirements necessitates a software structure which is readily modified. The ARPV software should be hierarchically modular so that design errors are discovered early in the design cycle and many error types are prevented altogether. Hierarchical modularity also promotes highly localized error/change effects so that individual software modules can be modified without introducing errors or affecting other modules.

[1] Kilpatrick, P.S., *et al.*, "All Semiconductor Distributed Aerospace Processor/Memory Study, Volume 1: *Avionics Processing Requirements*, Honeywell, Inc. Contract No. F33615-72-C-1709, performed for the Air Force Avionics Laboratory, WPAFB, Ohio, November 1972.

[2] Consolver, G., *et al.*, "Distributed Processor/Memory Architectures Design Program," Texas Instruments Incorporated, AFAL-TR-75-80, performed for the Air Force Avionics Laboratory.

2. Software Development Methodology

The software development methodology should assist in accomplishing the following tasks:

Receive system requirements and analyze them to produce a software design.

Implement the design in analytic code. This usually is accomplished by several different programmers.

Integrate the modules of code together to form a test process which is then evaluated for deficiency of logic, data flow and performance. Corrections are made by returning to appropriate steps in the above cycle.

One of the most important aspects of the overall effort is a clear and testable set of requirements. These requirements should be unambiguous and should be used as a guide throughout the software design, implementation and operational stages. At the requirements level, it is often observed that requirements are ambiguous in that they do not mean the same thing to the system designer and the software designers/programmers. Furthermore, during the long software development cycle and on into the operational phases, requirements change; some due to a better understanding of the nature of the process and some due to changes in application or mission requirements. It is clear that a software development methodology must readily accommodate changing requirements.

The processing requirements should then be partitioned into tasks. Traceability of individual tasks to the original requirements is important. During top-level design, a model of each task should be tested in a system network simulator in order to make efficient processor assignments and test the interrelationships among tasks so assigned. At this stage, task sequencing control and scheduling schemes should be tested to make sure that a suitable amount of computer capability has been allocated and that no task will create a bottleneck in the system. The tasks themselves should then be carried through an evolutionary design process in which they are refined using a top-down design approach. Each task should be tested against the system simulator at every stage of this successive refinement. The resulting modular structure should be maintained so that there is the utmost simplicity in the final structure itself. At each stage of refinement, a firm interface specification should be documented before any coding of the module begins. At the end of this evolutionary design, since testing has occurred at all stages and since every interface has been "designed", the software should, in fact, be operational with no need for integration in the standard sense.

3. System Simulator

Throughout the design process described above, there exists a need for a system simulator. The typical system simulator should consist of an integrated set of tools which aids the system designer at every stage of the process. Four basic model types can be used to represent software components in simulators:

Computer-independent models

Synthetic models

Functional models

Analytic models.

Computer independent models describe program execution dynamics by specifying counts of various operations, memory requirements, program input/outputs and subroutine calls and alternative program execution paths.

Synthetic models of programs are produced by merging the characteristics of the computer under consideration with the computer-independent model of the program.

The functional model of a program includes the synthetic model and the functional model of the computational procedure which is to be represented by the program.

The analytic model is the actual implementation of a program or task on the target configuration. Figure 3 summarizes the evolution of models and shows their temporal ordering during software development. Figure 4 shows the relationship between the hierarchical levels of simulators.

4. Executive Software

The use of distributed processing elements or remote terminals in the ARPV processing system dictates the need for a method of scheduling activities, transferring bus messages between elements on the bus and general system control. These operations are referred to as executive functions. The executive requirements for a multitask federated processing system are well known and will not be repeated here. This section will deal only with the executive requirements for a distributed processing network.

The role of the executive software within the context of the distributed system concept is to provide a set of basic control functions necessary to schedule avionic mission software routines and provide a common communication mechanism for inter-PE data transfers. Ideally, the executive should impose minimum computational overhead on the hardware resources while providing minimum but necessary control operations to ensure satisfactory performance of the PE network in accomplishing avionic processing in a timely manner. The distributed system executive must operate within the capabilities (and adhere to the restrictions) of the system hardware resources and the modes of the likely avionic system operation within a mission. In addition, the structure or organization of real-time avionic programs dictates that the executive provide the necessary means of scheduling, monitoring, and providing data set management between cooperating processing tasks.

The physical separation of PEs in a network requires that the executive provide a timely method of transmitting data between PEs. The need to reconfigure processing resources for the multimission ARPV imposes the requirement that the executive structure be adaptable to various topological interconnections with minimum modifications and maximum expectation that newly created control software will function properly.

5. Software Language—HOL Versus AL

Developers have been cautious and reluctant to utilize a HOL rather than AL to implement avionics software because of apparent investment costs, programmer retraining, and reduction in computer memory efficiency. Benefits of HOL are not as obvious as these costs, and developers are unwilling to risk such a major departure from established practices.

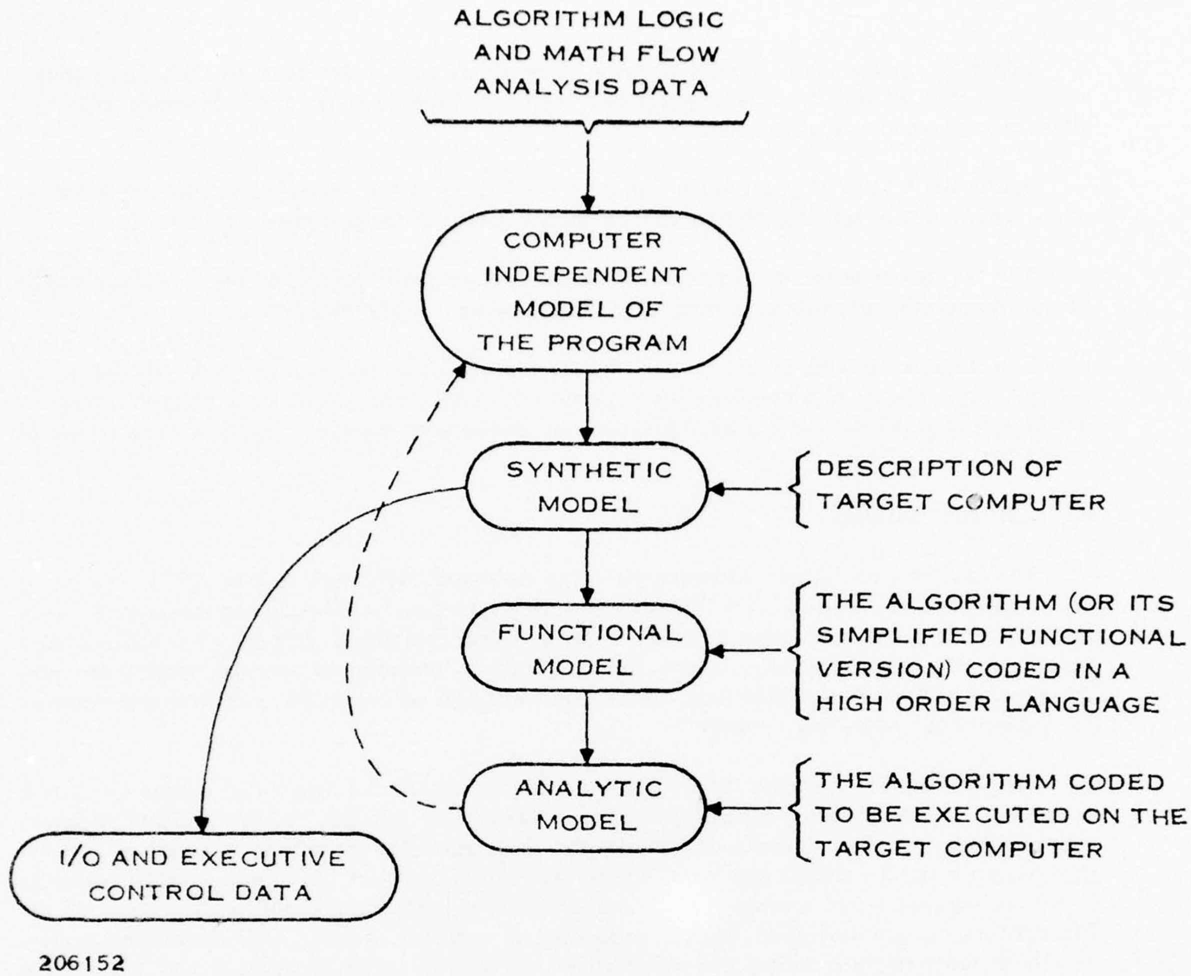

Figure 3. Evolution of Process Models

The real value of HOL systems lies in such factors as testability, hardware independence, programming flexibility, operational reliability, maintainability and lower development risk associated with software handover to new programmers, reduced training problems, software commonality, etc. These characteristics are relatively difficult to evaluate or compare in terms of dollar costs. For example, the assumption of few software changes would favor AL, while the assumption of many changes would favor HOL. How many software changes there actually will be over the life of a system depends not only on how well the system has been designed to satisfy operational requirements, but also on how fixed the requirements are, and on how readily the software may be safely changed.

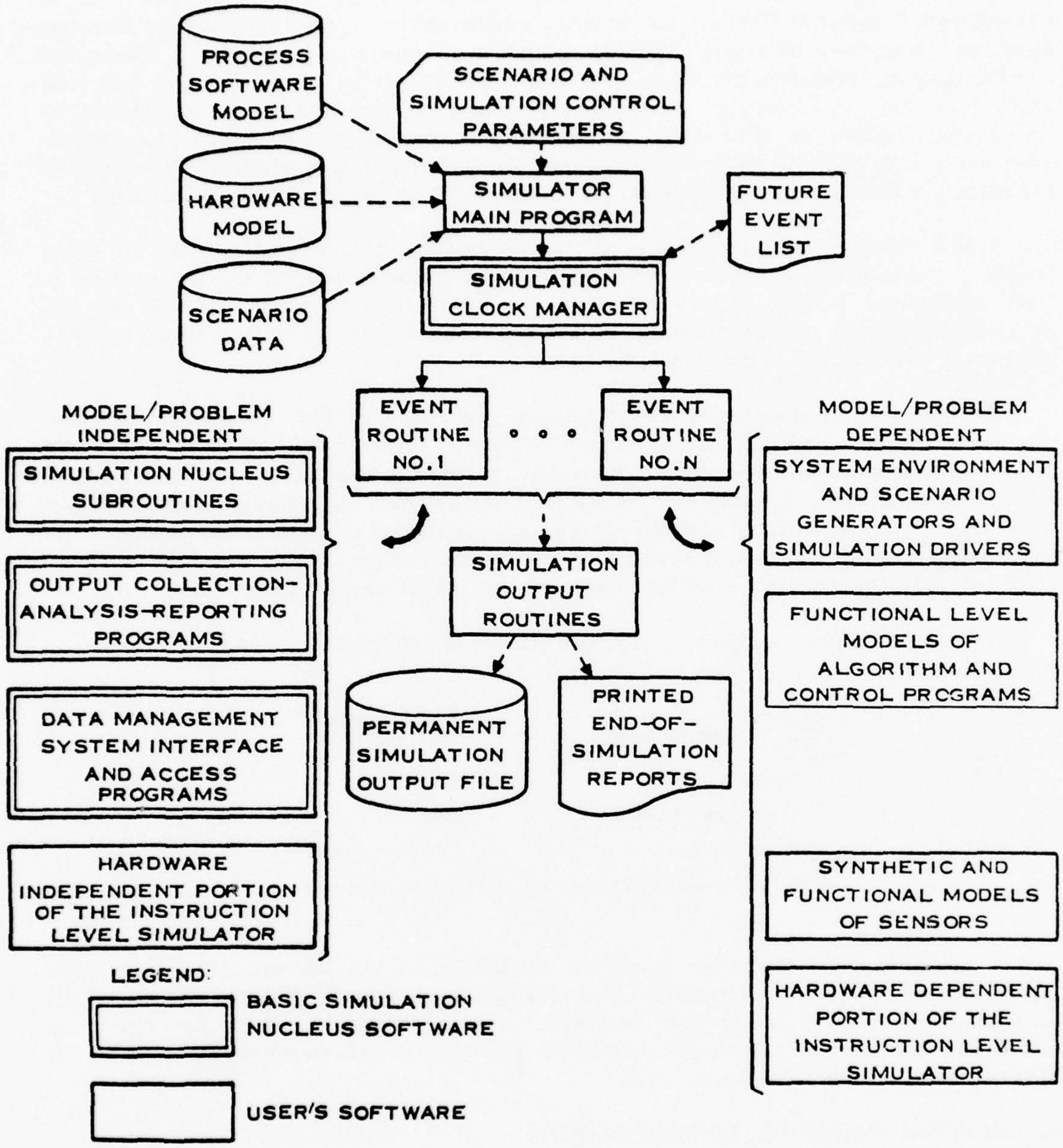

Figure 4. Overall Structure of the Relationship Between System Network, Functional and Instruction Level Simulators

An increasing amount of avionics software is now being written in HOL such as JOVIAL/J3B, a dialect of JOVIAL, the Air Force's command and control programming language. Based on comparison of typical computer output with functionally equivalent, hand-coded assembly language programs, it has been determined that a compiler can provide a machine code which is within 10–15 percent of the memory and execution time bounds established by hand-coded programs. In most cases for the ARPV application, the efficiency of computer-generated code is expected to be sufficient to satisfy overall system constraints. Where memory and execution time are critical, a program can be fine tuned by coding in assembly language.

A HOL, such as JOVIAL, lends itself to structured programming and thus has the added benefit of being self-documenting. Out-of-date software documentation is a major problem in many applications. Because of the small amount of detail (value of pages, variables, switches, etc.) necessary for the programmer to understand and retain to make a change, a structured HOL can be very cost effective in the operational phases.

Unfortunately, it is not practical to separate the effects of HOL from other computer parameters and no irrefutable conclusions can be drawn. However, the use of HOL in recent avionics applications has shown that HOL is practical, even in real-time systems, and carries a number of benefits. It has also been shown that the computer instruction repertoire affects efficiency more than HOL. In this respect, the only added cost of HOL would seem to be in added memory space. However, the continuing downward trend for memory costs while software costs rise, makes the relatively small decrease in efficient use of memory insignificant.

Some typical differences between HOL and AL can be summarized as follows:

Cost Category	**Cost Comparison HOL Versus AL**
System Checkout	Same
Programmer Training	Same
Documentation	5 percent savings
Code, Keypunch, Simulation	20 percent savings

At this time there is no firm answer to the HOL versus AL tradeoff. All of the various factors still need to be considered individually for each application considered. The size of the hardware buy, the type and cost of memories involved, complexity of the functions being executed in software, overall system complexity, and customer requirements are a few of the variables which must be considered.

C. GENERAL HARDWARE CONSIDERATIONS

This section deals with questions of hardware standardization and selection of microprocessor type for the distributed processing approach to the ARPV application.

1. Standard Modules

The ARPV avionic processing tasks span the spectrum from simple programmable controllers to high throughput applications. This overall problem can be solved in a number of ways including the mixed use of bit slices, 4-bit, 8-bit and/or 16-bit microprocessors in a distributed processing network. The advantages of a standard module approach are presented below.

In many past avionics applications, standardization of hardware has not been widely practiced. This situation cannot be totally criticized, for the state-of-the-art in computer systems in the past has not been sufficiently stable to permit standardization without significant performance penalty. In the past few years the state-of-the-art has stabilized to a degree, and previous experience has provided the historical lessons and insight required to develop meaningful guidelines for standardization on a family concept.

There are several factors which now suggest standardization on a single family of processors for a broad range of applications. First, computer architecture has stabilized sufficiently so that computer system performance is now more a function of specific implementation. Further, the realization has come and is supported at all levels of Government and industry that the total LCC of a computer system is often more a function of software and logistic costs than it is of original hardware acquisition cost. Also there is a continuing trend throughout industry toward standardization of both hardware and software. This approach permits sharing a common support software base and common hardware subsystems and modules across family lines. An example is the Texas Instruments family of 16-bit microprocessors (9900 series). Rather than develop unique architectures for the MOS (TMS 9900) and the I^2L (SBP 9900) implementation technologies, the architecture of an existing commercial 16-bit minicomputer (Texas Instruments 990) was used. The above factors, coupled with the continuing reduction of hardware costs, suggests the use of a family of relatively few machine classes for a broad range of processing applications.

Current information indicates that the cost of various size microprocessors will not vary significantly once a given device is mature and widely used. Thus, there is little to be gained in terms of reduced acquisition cost by mixing different size microprocessors in an avionic application. By far the dominant consideration is the effect on sustaining cost. A nonhomogeneous processing system, using several different types or sizes of microprocessors, will complicate the logistics problem, thereby increasing overall system LCC. The most cost-effective approach appears to be a homogeneous system in which a standard size and type microprocessor is selected which best satisfies overall requirements of the particular application. This standard choice should then be used throughout the distributed network for the individual partitioned tasks or functions within the avionic application.

2. Microprocessor Size

The foregoing discussion on standardization argues against mixing different size microprocessors in a typical avionics application. There are several factors to be considered in selecting the microprocessor size to be used as the standard processing element.

There exists in the typical avionics application some tasks where large blocks of data must be processed, or where speed and high resolution are needed. In such processing tasks, an 8-bit word length or less can be a serious handicap. A 16-bit microprocessor can reach external memory locations 2 bytes at a time and the longer length (16-bit) data words can easily accommodate 8-, 12-, 14-, and 16-bit converter resolutions.

TABLE 3. PERFORMANCE OF 16-BIT MICROPROCESSOR VERSUS 8-BIT MICROPROCESSORS

	Program Memory Requirements (bytes)			Assembler Statements			Execution Time (microseconds)				
Test Program	9900	8080	6800	9900	8080	6800	9900	8080	6800	SBP 9900 Instruction	Execution Time (microseconds)*
Input/output handler	24	28	17	9	17	7	71	79	49	Branch:	2.67
										Register to Register	
Character search	22	20	18	8	9	8	661	760	808	Add (words/bytes)	
										Register to Register	4.67
										Indirect to indexed	8.67
Computed go to	12	17	14	5	11	8	98	145	145	Multiply	
										Register to Register	17.33
Vector addition											
$A_N \rightarrow B_N = C_N$ (16)	20	29	46	5	20	22	537	1098	1866	Divide	
										Register to register	41.33
										Shift (left/right)	
										1 bit	4.67
										8 bits	9.33
Vector addition:											
$A_N \rightarrow B_N = C_N(8)$	20	23	40	5	14	22	537	738	936	Move data (words/bytes)	
										Register to register	4.67
										Register to directory/index	7.33
Shift right 5 bits	10	19	20	3	12	9	22	137	81	Load communications register unit (register to CRU)	
Move block	14	16	34	4	9	16	537	1262	2246	8 bits	12.00
										16 bits	17.33
Totals	122	152	189	39	92	92	2464	4219	6131	Store CRU (CRU to register)	
										8 bits	14.67
										16 bits	20.00

*3-MHz Clock Rate

Bus interface considerations also enter into the selection of microprocessor size. A typical message transfer on a MIL-STD-1553A bus consists of a command word, one or more data words, and a status word. The data information content of each of these word types is 16-bits. Therefore, a simplification in design complexity will result if the interface with MIL-STD-1553A protocol is designed for a 16-bit microprocessor rather than an 8-bit or other alternative.

The basic performance advantage of a 16-bit microprocessor over smaller machines can be demonstrated quantitatively. Benchmark tests, comparing the 16-bit SBP 9900 with the popular 8-bit 8080, and the 8-bit 6800 microprocessors are summarized in Table 3. Six tests are shown with comparisons made in program memory requirements, lines of assembler code and execution times. Results for the separate test programs are summed together, showing that the 16-bit microprocessor saves an average of at least 20 percent on program memory, with 58 percent fewer assembler statements, and an average execution time at least 42 percent faster.

The need for floating-point operations in some avionic processing tasks also affects the choice of microprocessor size. If floating-point algorithms are implented in software, a 16-bit microprocessor has definite execution time advantages over an 8-bit machine. For typical floating-point operations, the execution time for an 8-bit machine is 2 to 4 times that of a 16-bit machine. If a hardware floating-point arithmetic unit is used, there are no significant differences in the performance of a 16-bit versus an 8-bit machine.

Figure 5 shows the relative costs for a 16-bit processing system versus an 8-bit system. For large configurations, although CPU costs may be higher for the 16-bit than for the 8-bit

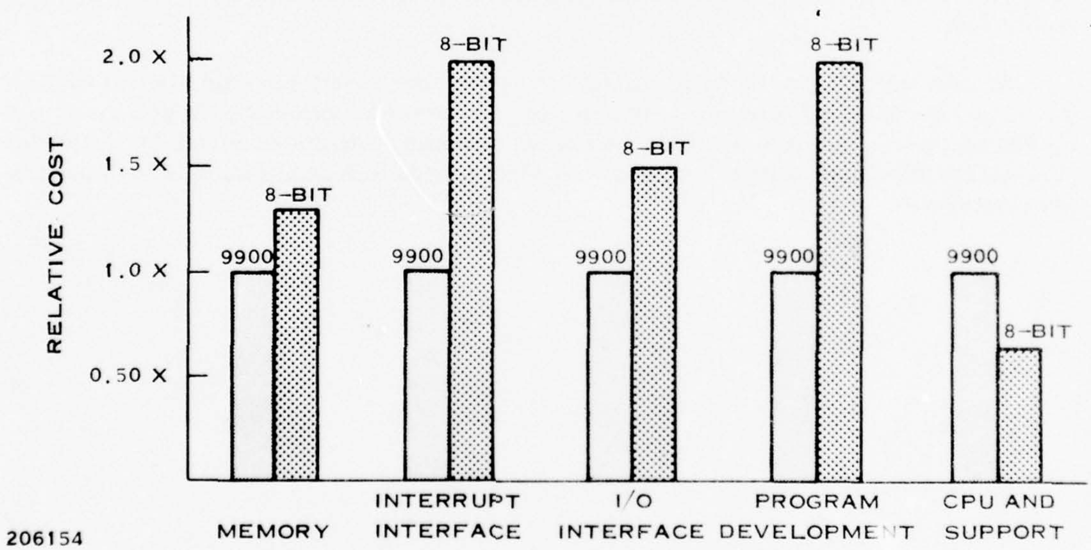

Figure 5. Relative Cost of 16-Bit Versus 8-Bit Microprocessor System

microprocessor, the overall 16-bit system costs considerably less due to the efficiency with which it handles large amounts of memory, I/O and interrupts.

For purposes of this study, the SBP 9900 is selected as a representative 16-bit standard microprocessor for use in the ARPV distributed processing networks. Standard processor, memory and I/O modules have been designed around the SBP 9900. Processing elements formed from these modules can perform many avionic processing tasks from simple sensor/actuator controllers to sophisticated high-precision, high-throughput applications. In addition, the SBP 9900 is a member of a family of compatible products (for commercial and military computer system applications) which are supported by a common software system including HOL compilers.

3. Bit Slice Processing Element

The use of bipolar bit slice processing elements is a possible approach for the ARPV avionics processing application. Two important advantages of the bit slice technique are:

- High throughput capacity which can be achieved in a modular building-block fashion, and
- Ability to emulate a wide variety of processor types.

Processor emulation may be a particularly significant feature for government applications where standardizing on a single instruction set or microprocessor type may not be feasible.

Although advantages of the bit slice technique are important, this approach does lead to increased LCC. Unlike a microprocessor, a bit slice processing element is only a section of a central processing unit (CPU). For example, a 16-bit microcomputer design requires four 4-bit slices for the CPU plus numerous other peripheral circuits for I/O functions. Because of the higher LCC, the bit slice approach was not considered for use in distributed processing networks in this study.

Bit slice processing elements also could be used to form a very powerful low-cost CPU for use in a centralized architecture. Although this is probably technically feasible, it is not considered to be a practical approach because of the many advantages offered by distributed processing architectures and the current strong trend toward such architectures in both industry and government.

SECTION III
DESCRIPTION OF THREE CANDIDATE SYSTEMS

A. INTRODUCTION

In order to design specific candidate processing systems it was necessary to first define representative ARPV mission scenarios and associated processing requirements. Scenarios were defined for a strike, a recce, and an EW mission. These scenarios and required mission functions are summarized in Appendix A of this report. A list of the core and mission-dependent equipment required to support the ARPV missions is shown in Appendix B. For purposes of this study only generic equipment types were considered. An equipment signal list also is included in Appendix B.

Algorithms required to support the ARPV missions are shown in Appendix C. Estimates of the processing requirements necessary to execute these algorithms form the basis for the design of each candidate ARPV processing system.

Functional diagrams for core and mission-specific avionics are shown in Figure 6 through Figure 9. These diagrams illustrate the functional relationship between ARPV equipment (rectangular blocks) and algorithms (square blocks).

The scope of this program was limited to investigating processing system architectures which utilize a single command/response time-division multiplex data bus meeting the requirements of MIL-STD-1553A. The advantages of this standardized bus approach for avionic applications are documented in contemporary studies and are not repeated here. Within this scope, three different processing systems were designed to meet the functional requirements shown in Figure 6 through Figure 9:

Centralized System

DP/M System

Hybrid System.

The Centralized system consists of a single central computer connected by a MIL-STD-1553A data bus to a number of remote terminals. This type of processing architecture was included in this study primarily to provide a reference for performance and LCC comparisons.

Most of the program effort was concentrated on two versions of a distributed processing approach to the ARPV processing problem. In the distributed processing approach, separate processing elements are interconnected by a MIL-STD-1553A data bus. The two distributed networks considered in this study are both homogeneous processing systems and differ only in the degree of partitioning of the total ARPV processing problem In the DP/M system, the problem is partitioned by major task while it is partitioned by functional area in the Hybrid system.

Reconfiguration of processing resources for specific missions was a basic design requirement for each candidate system. In all cases, reconfiguration is facilitated by the use of a standard data bus and by separating the processing system resources into core and mission-specific categories.

Bus loading for each candidate system was analyzed using a modified version of the System Network Simulator (SNS) developed under AFAL Contract F33615-74-C-1018. SNS results are summarized in this section of the report as part of the description of each candidate system. Additional detail on the SNS work is included as Appendix D.

1. Processing Requirements

From the material presented in Appendix A through Appendix C the specific algorithms required during individual mission segments can be determined. Table 4 through Table 6 show this information in a time-line analysis format for each mission.

Memory and throughput estimates for individual algorithms are shown in Table 7.* Individual algorithm throughput requirements, together with the previous charts showing algorithm activity in each mission segment, can be used to determine the total processing throughput requirement for each mission segment as shown in Table 8 through Table 10. Total memory requirements are shown in Table 11.

*The algorithm estimates are intended to be representative requirements established for system design purposes only. These estimates should not be interpreted as firm specifications for the ARPV application.

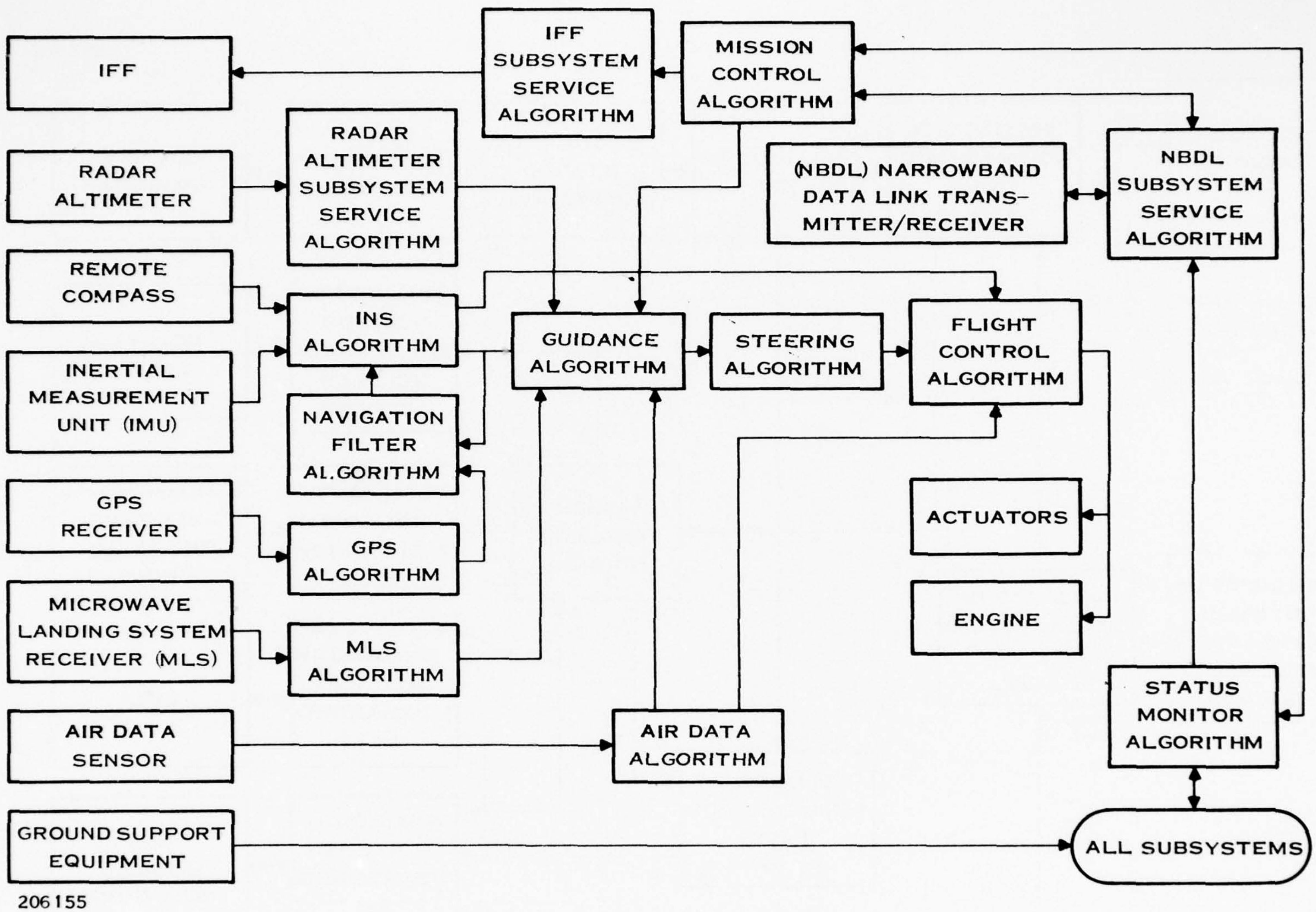

Figure 6. Core Avionics Functional Diagram

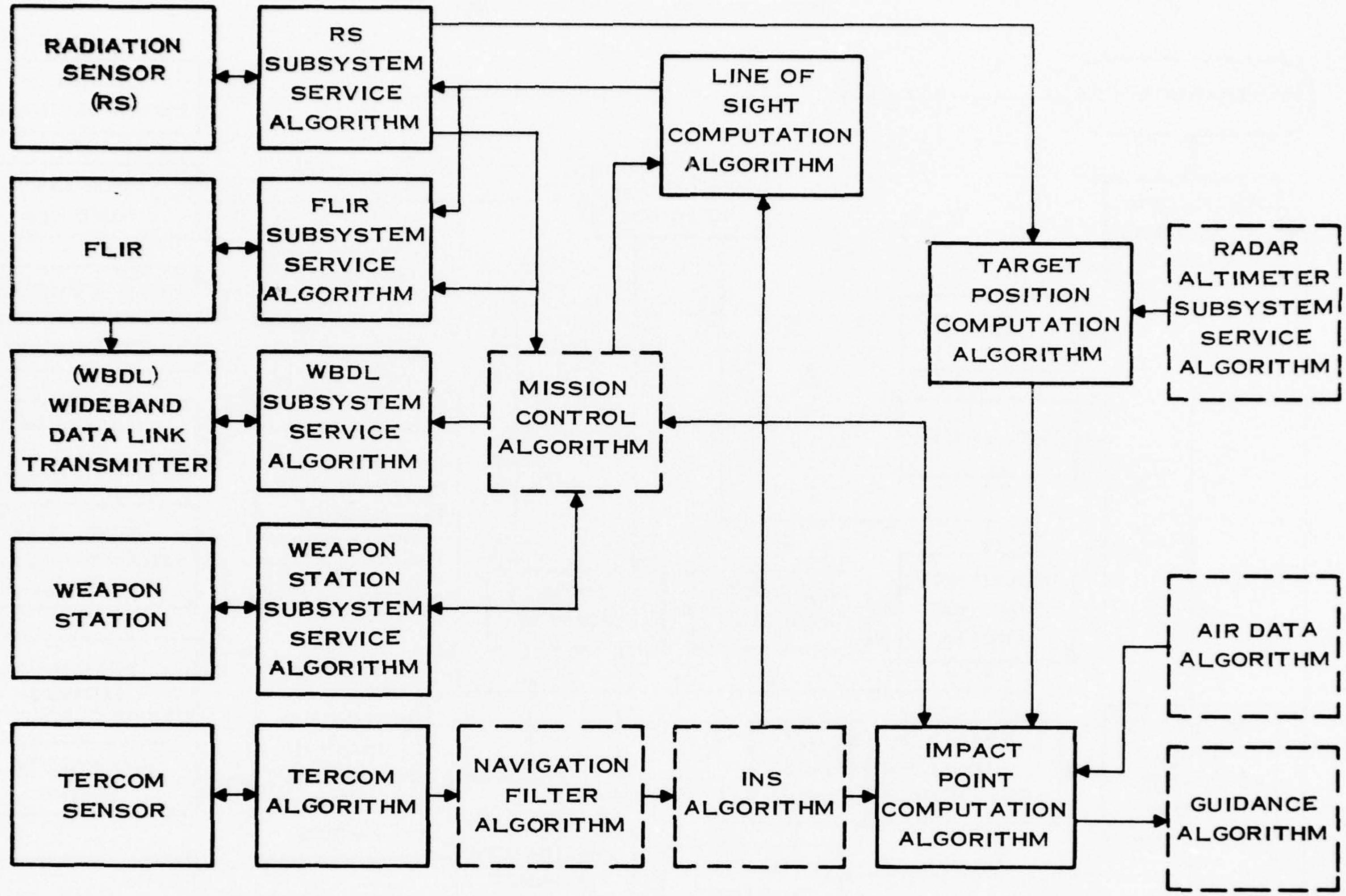

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Figure 7. Strike Mission Avionics Functional Diagram

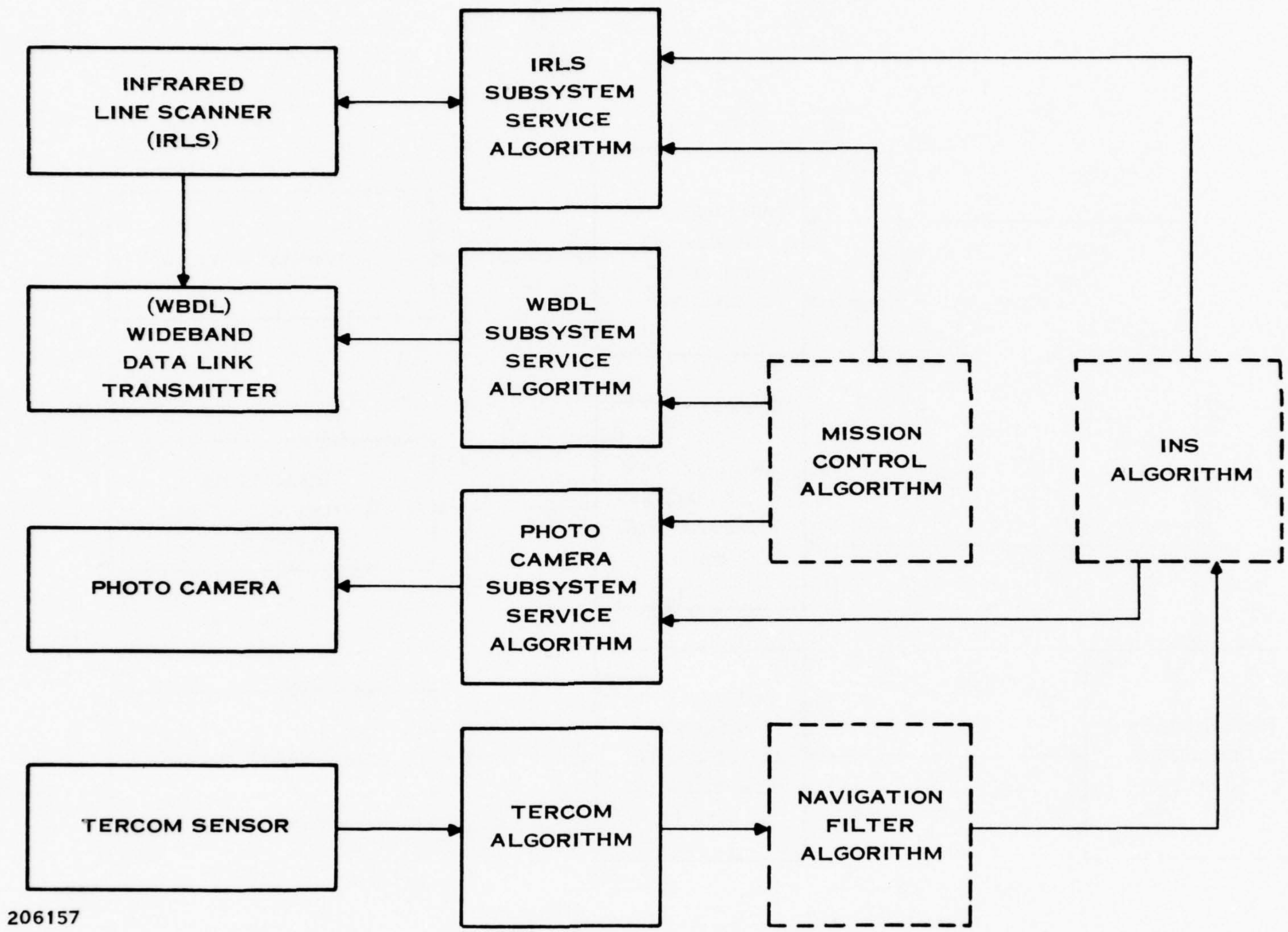


Figure 8. Recce Mission Avionics Functional Diagram

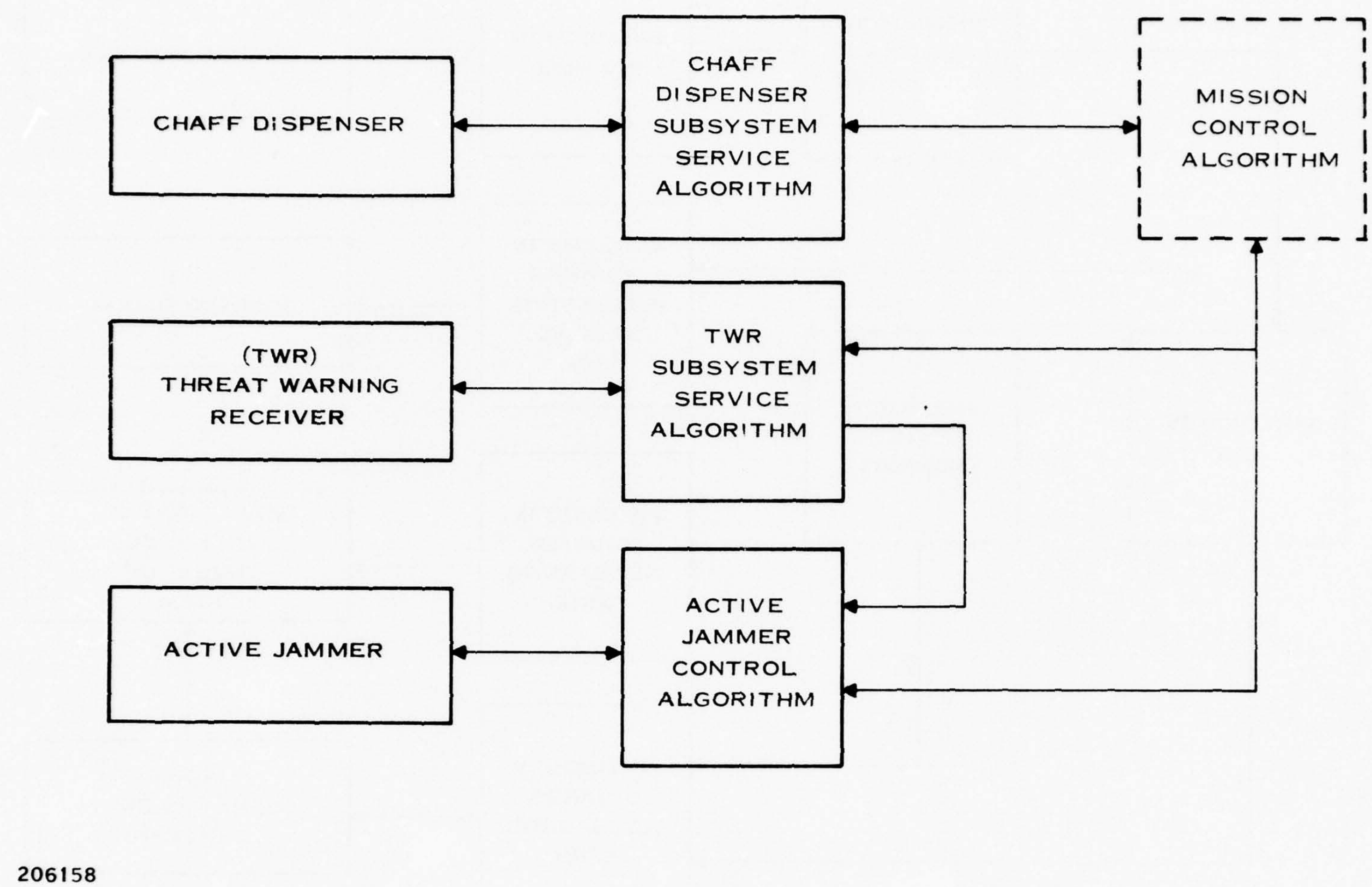


Figure 9. EW Mission Avionics Functional Diagram

TABLE 4. STRIKE MISSION TIME-LINE ANALYSIS

Algorithm	Mission Segment															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
INS (strapdown)			X	X	X	X	X	X	X	X	X	X	X	X		
Navigation Filter			X	X	X	X	X	X	X	X	X	X	X			
GPS			X	X	X	X					X	X	X			
Steering			X	X	X	X	X	X	X	X	X	X	X	X		
Flight Control			X	X	X	X	X	X	X	X	X	X	X	X		
Air Data			X	X	X	X	X	X	X	X	X	X	X	X		
Radar Altimeter Subsystem Service			X	X		X	X	X	X	X			X	X		
Mission Control			X	X	X	X	X	X	X	X	X	X	X	X		
Guidance			X	X	X	X	X	X	X	X	X	X	X	X		
MLS													X	X		
Status Monitor			X	X	X	X	X	X	X	X	X	X	X	X		
NBDL Subsystem Service			X	X	X	X	X	X	X	X	X	X	X	X		
IFF Subsystem Service											X	X				
Aircraft Instrumentation Subsystem Service			X	X	X	X	X	X	X	X	X	X	X	X		
Bulk Storage Subsystem Service			X	X	X	X	X	X	X	X	X	X	X	X		
Bus Control			X	X	X	X	X	X	X	X	X	X	X	X		
Line-of-Sight Computation							X	X	X							
Target Position Computation								X	X							
Impact Point Computation								X	X							
FLIR Subsystem Service							X	X	X							
Radiation Sensor Subsystem Service							X	X	X							
TERCOM							X	X		X						
WBDL Subsystem Service					X		X	X								
Weapon Station Subsystem Service							X	X	X							

TABLE 5. RECCE MISSION TIME-LINE ANALYSIS

Algorithm	Mission Segment																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
INS (strapdown)			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		
Navigation Filter			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		
GPS			X	X	X	X									X	X	X			
Steering			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		
Flight Control			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		
Air Data			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		
Radar Altimeter Subsystem Service			X	X		X	X	X	X	X	X	X	X	X			X	X		
Mission Control			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		
Guidance			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		
MLS																	X	X		
Status Monitor			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		
NBDL Subsystem Service			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		
IFF Subsystem Service															X	X				
Aircraft Instrumentation Subsystem Service			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		
Bulk Storage Subsystem Service			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		
Bus Control			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		
TERCOM							X	X	X	X	X	X	X	X						
WBDL Subsystem Service					X			X		X		X								
IR Line Scanner Subsystem Service						X		X		X		X								
Photo Camera Subsystem Service						X		X		X		X								

TABLE 6. EW MISSION TIME-LINE ANALYSIS

Algorithm	Mission Segment														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
INS (strapdown)			X	X	X	X	X	X	X	X	X	X	X		
Navigation filter			X	X	X	X	X	X	X	X	X	X	X		
GPS				X	X	X	X	X	X	X	X	X			
Steering			X	X	X	X	X	X	X	X	X	X	X		
Flight Control			X	X	X	X	X	X	X	X	X	X	X		
Air Data			X	X	X	X	X	X	X	X	X	X	X		
Radar Altimeter Subsystem Service			X	X								X	X		
Mission Control			X	X	X	X	X	X	X	X	X	X	X		
Guidance			X	X	X	X	X	X	X	X	X	X	X		
MLS												X	X		
Status Monitor			X	X	X	X	X	X	X	X	X	X	X		
NBDL Subsystem Service			X	X	X	X	X	X	X	X	X	X	X		
IFF Subsystem Service											X	X			
Aircraft Instrumentation Subsystem Service			X	X	X	X	X	X	X	X	X	X	X		
Bulk Storage Subsystem Service			X	X	X	X	X	X	X	X	X	X	X		
Bus Control			X	X	X	X	X	X	X	X	X	X	X		
Chaff Dispenser Subsystem Service						X	X	X							
Threat Warning Receiver Subsystem Service						X	X	X	X						
Active Jammer Control							X	X	X						

TABLE 7. ALGORITHM PROCESSING REQUIREMENTS

Algorithm	Memory (16-Bit Words) Instructions	Data	Total	Throughput (KOPS)
Core				
INS (strapdown)	3,000	500	3,500	65
Navigation Filter	1,300	2,300	3,600	35
GPS	11,500	2,100	13,600	68
Steering	720	50	770	11.5
Flight Control	2,750	600	3,350	45
Air Data	560	75	635	6
Radar Altimeter Subsystem Service	150	30	180	0.5
Mission Control	3,300	2,000	5,300	15
Guidance	2,200	300	2,500	7
MLS	660	100	760	7.5
Status Monitor	550	500	1,050	3
Narrowband Data Link Subsystem Service	550	500	1,050	3
IFF Subsystem Service	150	50	170	0.5
Bus Control	1,000	2,000	3,000	30
Bulk Storage Subsystem Service	50	20	70	0.5
Aircraft Instrumentation Subsystem Service	70	30	100	0.5
Mission Specific				
Line-of-Sight Computation	330	50	380	5
Target Position Computation	330	50	380	5
Impact Point Computation	1,760	200	1,960	71
FLIR Subsystem Service	600	100	700	3
Radiation Sensor Subsystem Service	600	100	700	2
TERCOM	2,450	2,000	4,450	70
Wideband Data Link Subsystem Service	170	50	220	0.5
Weapon Station Subsystem Service	550	100	650	3
IR Line Scanner Subsystem Service	220	50	270	1
Photo Camera Subsystem Service	220	50	270	1
Chaff Dispenser Subsystem Service	330	60	390	1
Threat Warning Receiver Subsystem Service	400	100	500	1.5
Active Jammer Control	880	200	1,080	7

TABLE 8. STRIKE MISSION THROUGHPUT ANALYSIS

Algorithm	Throughput Per Segment (KOPS)											
	3	4	5	6	7	8	9	10	11	12	13	14
INS	65	65	65	65	65	65	65	65	65	65	65	65
Navigation Filter	35	35	35	35	35	35	35	35	35	35	35	35
GPS	68	68	68	68					68	68	68	
Steering	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5
Flight Control	45	45	45	45	45	45	45	45	45	45	45	45
Air Data	6	6	6	6	6	6	6	6	6	6	6	6
Radar Altimeter	0.5	0.5		0.5	0.5	0.5	0.5	0.5			0.5	0.5
Mission Control	15	15	15	15	15	15	15	15	15	15	15	15
Guidance	7	7	7	7	7	7	7	7	7	7	7	7
MLS											7.5	7.5
Status Monitor	3	3	3	3	3	3	3	3	3	3	3	3
NBDL	3	3	3	3	3	3	3	3	3	3	3	3
IFF									0.5	0.5		
Aircraft Instrumentation	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Bulk Storage	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Bus Control	30	30	30	30	30	30	30	30	30	30	30	30
Line-of-Sight Computation					5	5	5					
Target Position Computation						5	5					
Impact Point Computation						71	71					
FLIR					3	3	3					
Radiation Sensor					2	2	2					
TERCOM					70	70		70				
WBDL			0.5		0.5	0.5						
Weapon Station					3	3	3					
Total Throughput (KOPS)	290	290	290	290	305.5	381.5	311	292	290	290	297.5	229.5

TABLE 9. RECCE MISSION THROUGHPUT ANALYSIS

Algorithm	Throughput Per Segment (KOPS)															
	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
INS	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65
Navigation Filter	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35
GPS	68	68	68	68									68	68	68	
Steering	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5
Flight Control	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45
Air Data	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
Radar Altimeter	0.5	0.5		0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5			0.5	0.5
Mission Control	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
Guidance	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
MLS															7.5	7.5
Status Monitor	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
NBDL	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
IFF													0.5	0.5		
Aircraft Instrumentation	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Bulk Storage	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Bus Control	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
TERCOM					70	70	70	70	70	70	70	70				
WBDL			0.5			0.5		0.5		0.5						
IR Line Scanner				1		1		1		1						
Photo Camera				1		1		1		1						
Total Throughput (KOPS)	290	290	290	292	292	294.5	292	294.5	292	294.5	292	292	290	290	297.5	229.5

TABLE 10. EW MISSION THROUGHPUT ANALYSIS

Algorithm	Throughput Per Segment (KOPS)										
	3	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
INS	65	65	65	65	65	65	65	65	65	65	65
Navigation Filter	35	35	35	35	35	35	35	35	35	35	35
GPS		68	68	68	68	68	68	68	68	68	
Steering	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5
Flight Control	45	45	45	45	45	45	45	45	45	45	45
Air Data	6	6	6	6	6	6	6	6	6	6	6
Radar Altimeter	0.5	0.5								0.5	0.5
Mission Control	15	15	15	15	15	15	15	15	15	15	15
Guidance	7	7	7	7	7	7	7	7	7	7	7
MLS										7.5	7.5
Status Monitor	3	3	3	3	3	3	3	3	3	3	3
NBDL	3	3	3	3	3	3	3	3	3	3	3
IFF									0.5	0.5	
Aircraft Instrumentation	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Bulk Storage	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Bus Control	30	30	30	30	30	30	30	30	30	30	30
Chaff Dispenser				1	1	1					
Threat Warning Receiver				1.5	1.5	1.5	1.5				
Active Jammer Control					7	7	7				
Total Throughput (KOPS)	220	290	289.5	292	299	299	298	290	290	298	229.5

TABLE 11. TOTAL ALGORITHM MEMORY REQUIREMENTS

	Memory (16-Bit Words)		
Mission	Core Functions	Mission-Dependent Functions	Total
Strike	39,635	9,440	49,075
Recce	39,635	5,210	44,845
EW	39,635	1,970	41,605

2. Modular Processing Element

The following standard modules are used to form PEs for both the DP/M and Hybrid distributed processing systems:

Microprocessor Module (MPM)

Program Memory Module (PMM)

Data Memory Module (DMM)

Serial Bus Interface Module (SBIM)

I/O Interface Module (IOIM)

Voltage Regulator Module (VRM).

The functional organization of modules within a PE is shown in Figure 10. The physical characteristics of individual modules are shown in Table 12.

TABLE 12. PROCESSING ELEMENT MODULE CHARACTERISTICS

Module	Weight (pounds)	Power (watts)	Width (inches)	Length (inches)	Height (inches)
MPM (one PWB)	0.5	4.75	0.58	5.62	4.8
SBIM (Digital – one PWB)	0.5	5.19	0.58	5.62	4.8
(Analog – one PWB)	0.5	5.76	0.58	5.62	4.8
IOIM (one PWB)	0.5	2.3	0.58	5.62	4.8
PMM (one PWB)	0.5	2.5	0.58	5.62	4.8
DMM (one PWB)	0.5	3.3	0.58	5.62	4.8
VRM (one PWB)	1.5	*	0.58	5.62	4.8
Connector Board	1.32	NA	2.25	19.56	NA
Long Quarter ATR	2.5	NA	2.25	19.56	7.62
PWB Guides	1.6	NA	0.5	0.5	4.8
Mounting Hardware	**	NA	NA	NA	NA

*50 percent of total PE power
**10 percent of total PE weight

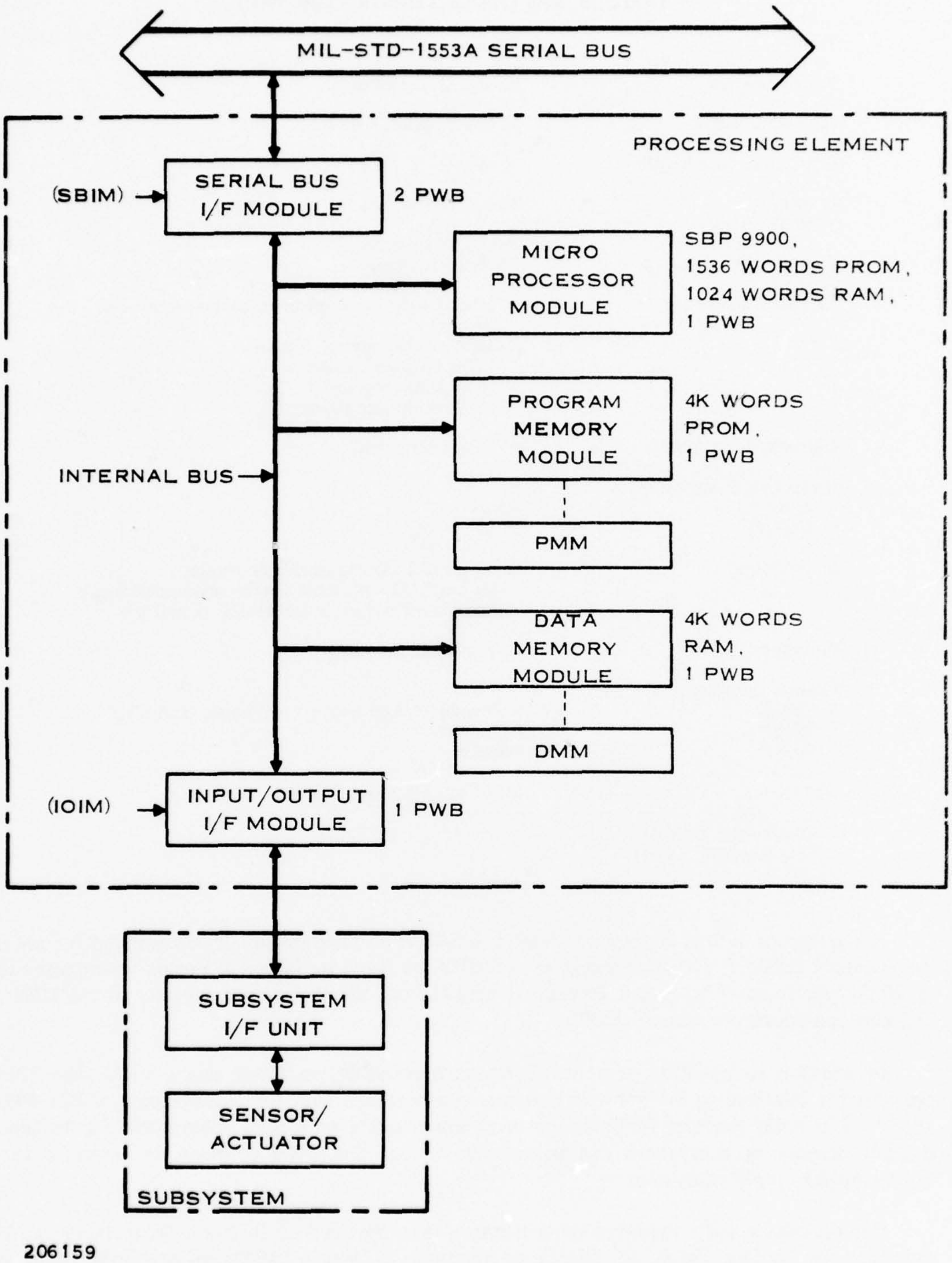


Figure 10. Processing Element Functional Organization

TABLE 13. MPM CHARACTERISTICS (SBP 9900)

Type	Parallel
Number system	Binary, 2's complement
Data word length	16 bits including sign
Instruction word length	16 bits
Memory	Addressable to 32K
MPM capacity	
PROM*	1536 16-bit words
RAM**	1024 16-bit words
Register complement	16 general registers per program context located in memory 3 user accessible internal registers: 16-bit program counter 16-bit status register 16-bit workspace pointer
Instruction repertoire	69 basic instructions
Instruction execution times	
Add	3.5 μs
Multiply	13 μs
Input/Output	16-bit parallel I/O addressable as memory. Bit serial I/O with 4096 directly addressable input bits and 4096 directly addressable output bits.
Interrupts	16 prioritized interrupts
Physical characteristics	
Size	0.58 width × 5.62 length × 4.8 height (inches)
Weight	0.5 pound
Power	500 mW
Cost	$1163 in quantities of 5,000

*Six chips (512 × 8 bits)
**Five chips (1024 × 4 bits)

For purposes of this study, the 16-bit I^2L SBP 9900 microprocessor was selected for use in the standard MPM. The characteristics of the MPM are listed in Table 13. For an instruction mix of 80 percent short (3.5 μs) and 20 percent long (13 μs), the throughput capacity of the MPM is 185 kilo operations per second (KOPS).

In addition to an MPM, a basic PE contains an SBIM, an IOIM, and a VRM. The SBIM provides for interface to the network data bus in accordance with the requirements of MIL-STD-1553A. The IOIM provides for interface to external ARPV sensors or subsystems. Up to seven separate sensors or subsystems can be accommodated. The VRM provides for interface to a central power supply subsystem.

For processing tasks requiring more memory than provided in the basic PE, memory can be expanded by adding PMMs or DMMs as required. A single PMM provides 4096 words of nonvolatile programmable read-only memory (PROM). A single DMM provides 4096 words of

TABLE 14. PE CHARACTERISTICS

	Basic PE	Fully Expanded PE
Volume (in^3)	335	335
Weight (pounds)	10	12
Power (watts)	27	45
Cost*	$4,100	$7,300

*In quantities of 5,000

read/write random-access memory (RAM). In addition to the four basic modules, a fully expanded PE contains four memory modules (any mix of PMMs and DMMs). The characteristics of a basic PE and a fully expanded PE are summarized in Table 14.

Both the DP/M and Hybrid processing networks interface with the aircraft prime power source through a power supply subsystem as shown in Figure 11. The power supply subsystem consists of two power supply modules, each providing five separate power output channels. Each output channel provides the power requirements for up to three fully expanded PEs (150 watts maximum). The power supply subsystem includes an auxiliary battery pack capable of providing 1.5 kVA (30 volts at 50 amperes) for a minimum period of 10 seconds. The battery pack is included in order to sustain PE power during possible transient periods as required by MIL-STD-704A. All PEs, power supply modules, and the auxiliary battery pack are contained in Long Quarter ATR cases (7.625 inches X 2.25 inches X 19.562 inches). Battery pack weight is approximately 30 pounds; each power supply module weighs approximately 20 pounds.

An example of the PE task-assignment procedure used in this study is provided here to illustrate how memory and throughput loading are determined. Assume that the INS (strapdown)

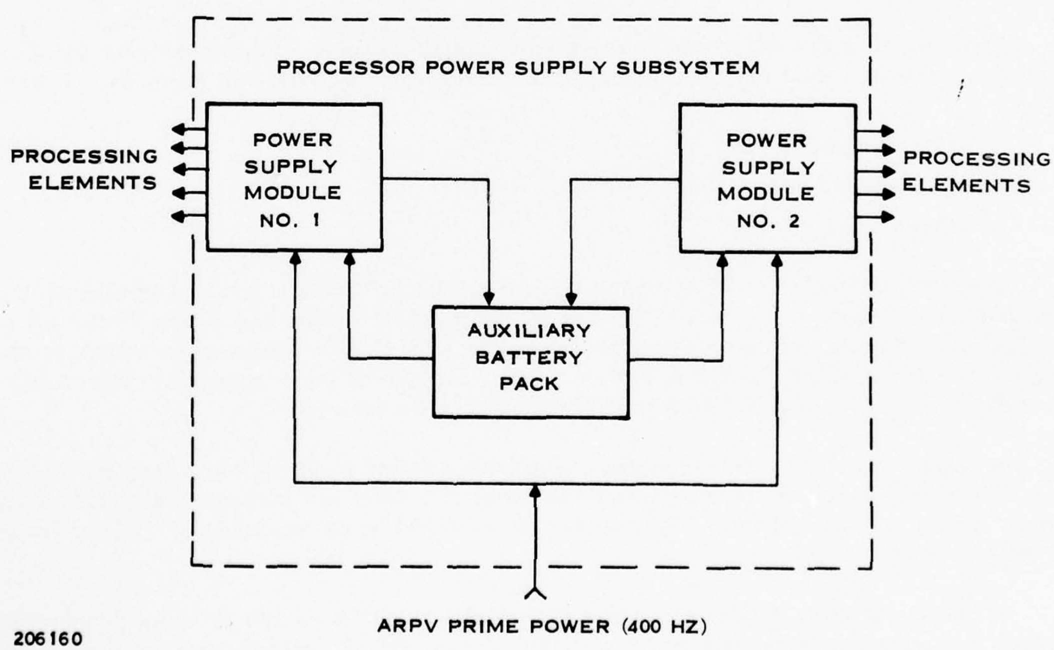


Figure 11. Power Supply Subsystem for Distributed Network

and Navigation Filter algorithms are assigned to one PE. From Table 7, the algorithm memory requirements are 4300 words PROM (instruction) and 2800 words RAM (data).

Each PE is controlled by a local table-driven executive with appropriate task-dependent table data. For this executive, 500 words of instruction memory are required plus 80 words of data memory for each separate algorithm to be executed. Therefore, the total PE memory required is 4800 words of PROM and 2960 words of RAM. In order to meet these requirements, one PMM and one DMM are required in addition to the memory available on the MPM. Therefore, the following module complement is required for this PE:

MPM

SBIM

IOIM

VRM

PMM (1)

DMM (1)

Utilization of available PROM is 85 percent (4800/5632) and utilization of RAM is 58 percent (2960/5120).

Also, from Table 7, the throughput requirement for these two algorithms is 100 KOPS. The local executive throughput requirement is taken as 10 percent of the total algorithm load. Therefore, utilization of available throughput is 59 percent (110/185). From Table 12 the weight of this PE is 11 pounds with a power requirement of 36 watts.

3. Ground Support Equipment

There are no major differences in the ground support equipment requirements for the three processing systems considered in this study. Ground support equipment will be required at three levels:

Organizational Level

Intermediate Level

Depot Level.

At the organizational or flight line level, each processing system is designed so that self-test and built-in test (BIT) will detect 99 percent of the probable failures and isolate 94 percent of the detected failures to the proper line removable unit (LRU). Maintenance action at the organizational level will be limited to replacing LRUs. Equipment for programming characteristics of the specific mission also will be required at the organizational level.

At the intermediate level, the design goal is fault isolation to the defective shop replaceable unit (SRU) for 90 percent of all malfunctions using automatic test equipment and BIT in the LRUs. Isolation to the defective SRU and one other should be accomplished for 100 percent of all malfunctions.

At the depot level, SRUs determined repairable will be tested and defective components isolated by using automatic test equipment. The design goal is isolation to 4 components for

80 percent of the possible faults, 8 components for 95 percent of possible faults and 10 components for 100 percent of possible faults.

B. CENTRALIZED SYSTEM

The computer for the Centralized system must meet two basic requirements–total memory size and peak throughput. From Table 8 through Table 10, a peak throughput requirement of 381.5 KOPS occurs during segment 8 of the strike mission. From Table 11, the maximum algorithm memory requirement is 49,075 words for the strike mission.

For purposes of this program, the Texas Instruments MARC IV16-bit computer is selected for use in the Centralized processing system. The MARC IV is considered to be representative of several currently available military computers which can satisfy the above processing requirement. The MARC IV includes a serial bus interface, 64K words of core memory, and a power supply. Additional detail on the MARC IV is shown in Table 15. For an instruction mix of 80 percent short (1 μs) and 20 percent long (5 μs), the throughput capacity of the MARC IV is 555 KOPS.

Block diagrams of the Centralized system are shown in Figure 12 through Figure 14 for the three mission configurations. The remote terminal interfaces shown in these block diagrams provide for interface between the network bus and the ARPV subsystems. In terms of complexity, a remote terminal interface is equivalent to an SBIM (two printed wiring board) plus additional control logic. Therefore, for purposes of this study, the following characteristics are assumed for each remote terminal interface:

Three printed wiring boards

Power–23 watts

Weight–3 pounds

Volume–94.5 in^3.

Including provisions for a relatively complex multitask executive, the processing requirements for the Centralized system are 51,200 words of memory plus a peak throughput of 411 KOPS. Therefore, utilization of available memory is 78 percent and utilization of available throughput is 74 percent. The capacity of the Centralized system can be expanded by adding another MARC IV to the system or by adding remote terminals which contain processing resources.

The peak bus traffic for the strike configuration of the Centralized system was determined using the SNS. Major components of the peak bus traffic during segment 8 of the strike mission are:

Total Traffic	39.65 kbps (kilobits per second)
Traffic Utilized for Data	24.80 kbps (62.55 percent)
Traffic Utilized for Header	13.20 kbps (33.29 percent)
Traffic Utilized for Gap	1.65 kbps (4.16 percent)

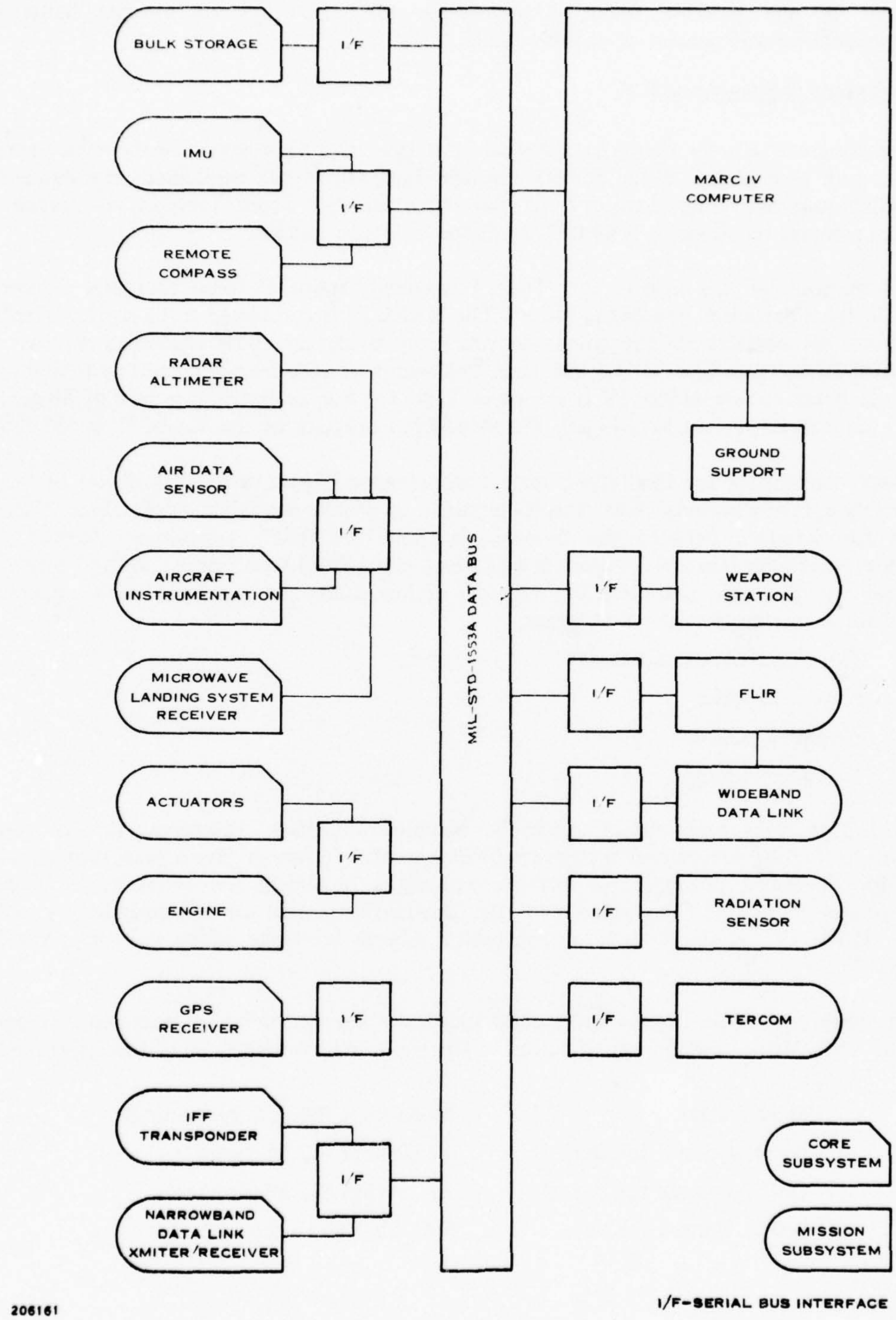


Figure 12. Centralized System–Strike Configuration

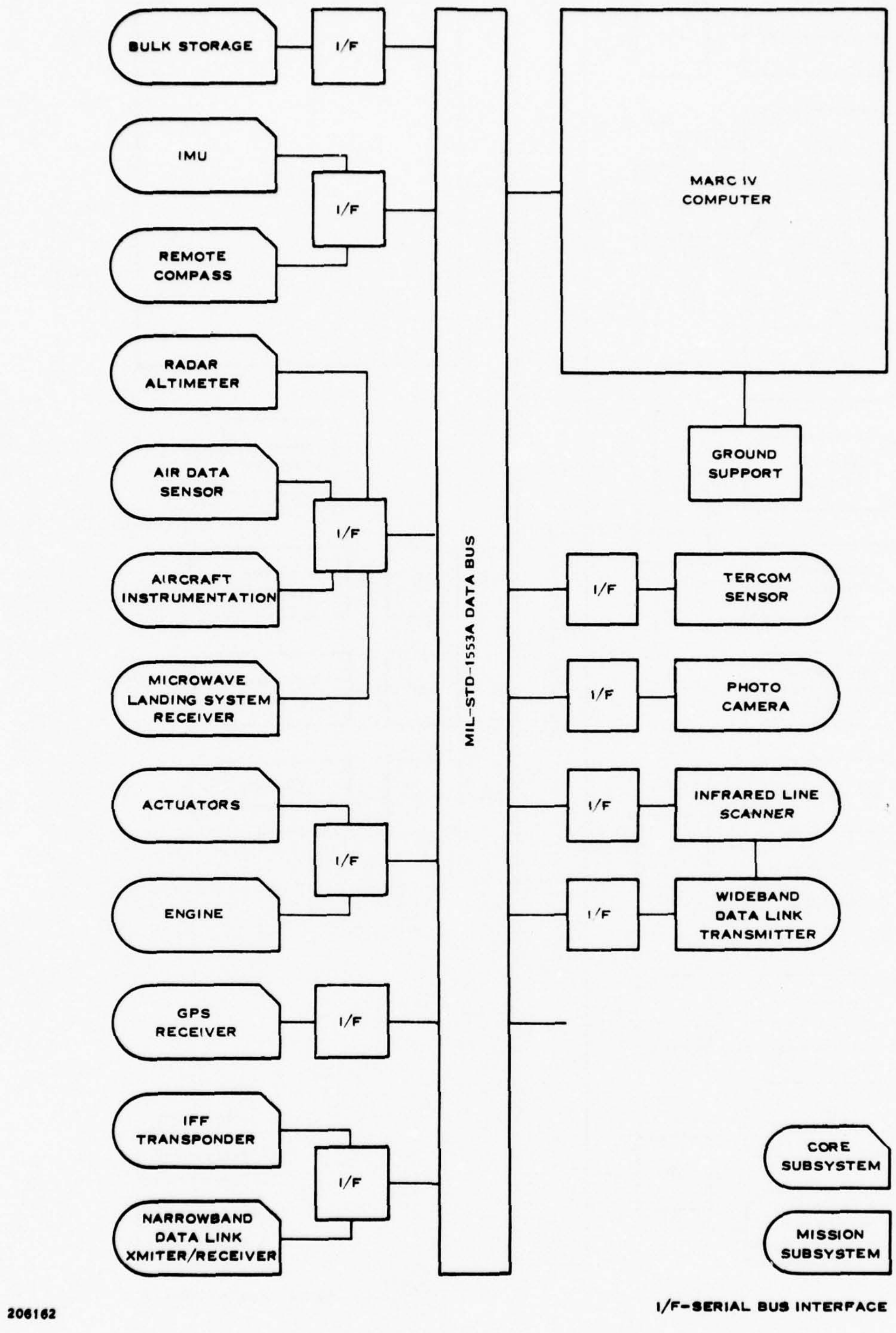


Figure 13. Centralized System–Recce Configuration

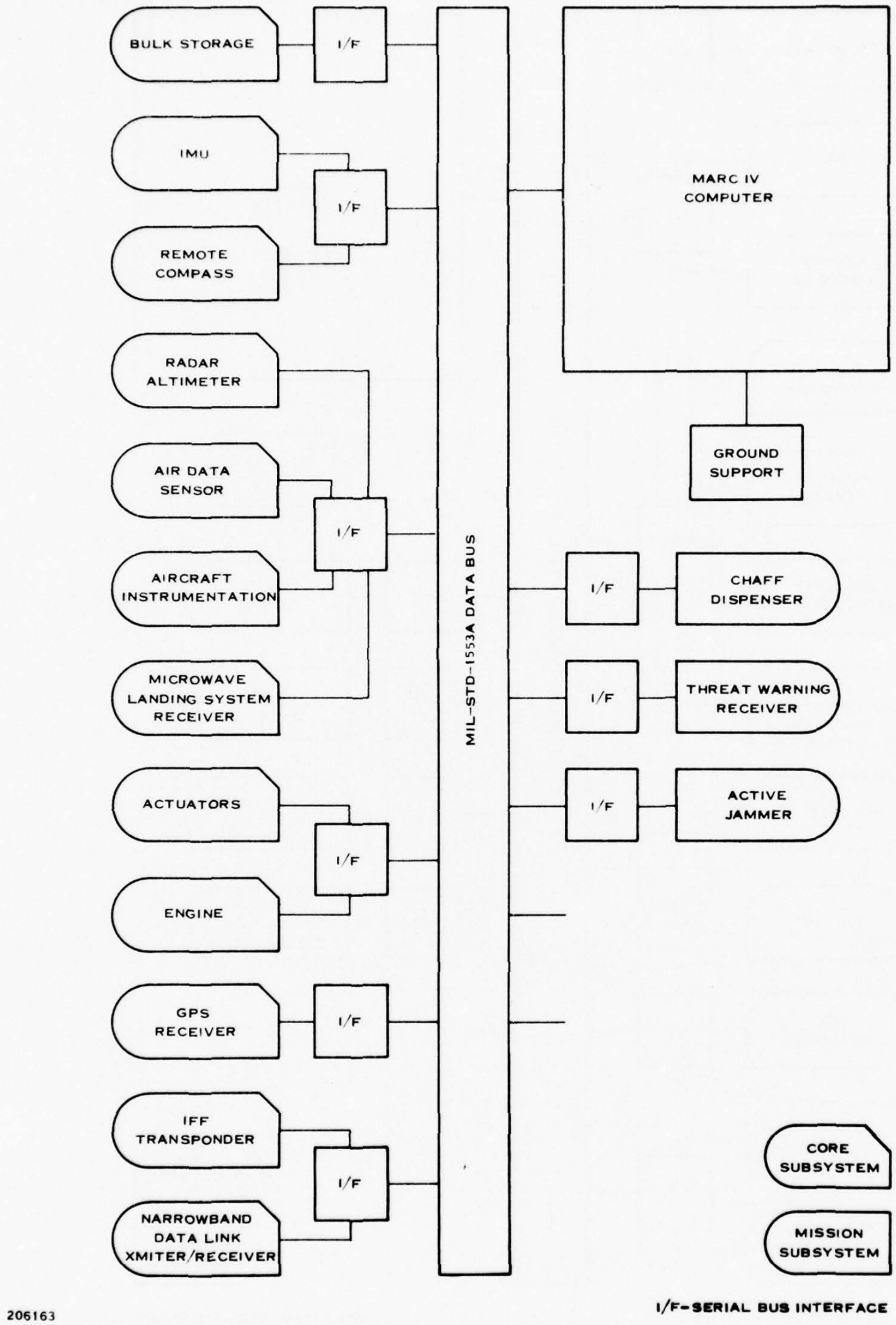


Figure 14. Centralized System–EW Configuration

TABLE 15. MARC IV CHARACTERISTICS

Type	Parallel
Number system	Binary, 2's complement
Data word length	16 bits and 32 bits
Instruction word length	16 bits and 32 bits
Memory (Core)	Expandable to 64K words
Access line	460 nanoseconds
Register complement	8 16-bit general registers 2 16-bit base registers 4 floating point registers User-accessible status words consisting of four 16-bit words: Program counter Overflow and condition code register Interrupt mask
Instruction repertoire	81 basic instructions
Instruction execution times	
Add	1 μs
Multiply	5 μs
Input/Output	1 16-bit parallel bilateral channel 3 serial channels consisting of two data buses each 1 serial channel for maintenance interface
Interrupts	24 prioritized interrupts
Physical characteristics	
Weight	110 pounds
Volume	4110 in^3
Power	500 watts
Cost	$80,000 in quantities of 500

C. DP/M SYSTEM

The primary guideline in designing the DP/M processing system is partitioning the avionic computational requirements by task. Each major task and/or subsystem (sensor/actuator) of the aircraft is assigned its own PE. Inter-PE communication is achieved via the network bus.

Block diagrams of the DP/M system are shown in Figure 15 through Figure 17 for the three mission configurations. Table 16 provides a summary of DP/M system characteristics. Characteristics of individual PEs within the DP/M system are shown in Table 17. Task assignments and module complement for core and mission-specific PEs are shown in Table 18 through Table 21.

Utilization of processing resources within the DP/M system is shown below:

	Percent Utilization		
DP/M Network	**PROM Memory**	**RAM Memory**	**Throughput**
Core	72	43	14.7
Strike	58.5	35.7	18.9
Reece	49.4	30.2	10.8
EW	67.5	19.5	1.9

Margin for growth is more than adequate, considering that further PROM or RAM can be added to existing PEs very easily. For unusual requirements that may arise, the system can be expanded by adding new PEs.

Peak bus traffic for segment 8 of the strike mission is summarized below for the DP/M strike configuration:

Total traffic	101.25 kbps
Traffic utilized for data	52.20 kbps (51.56 percent)
Traffic utilized for header	43.60 kbps (43.06 percent)
Traffic utilized for gap	5.45 kbps (5.38 percent)

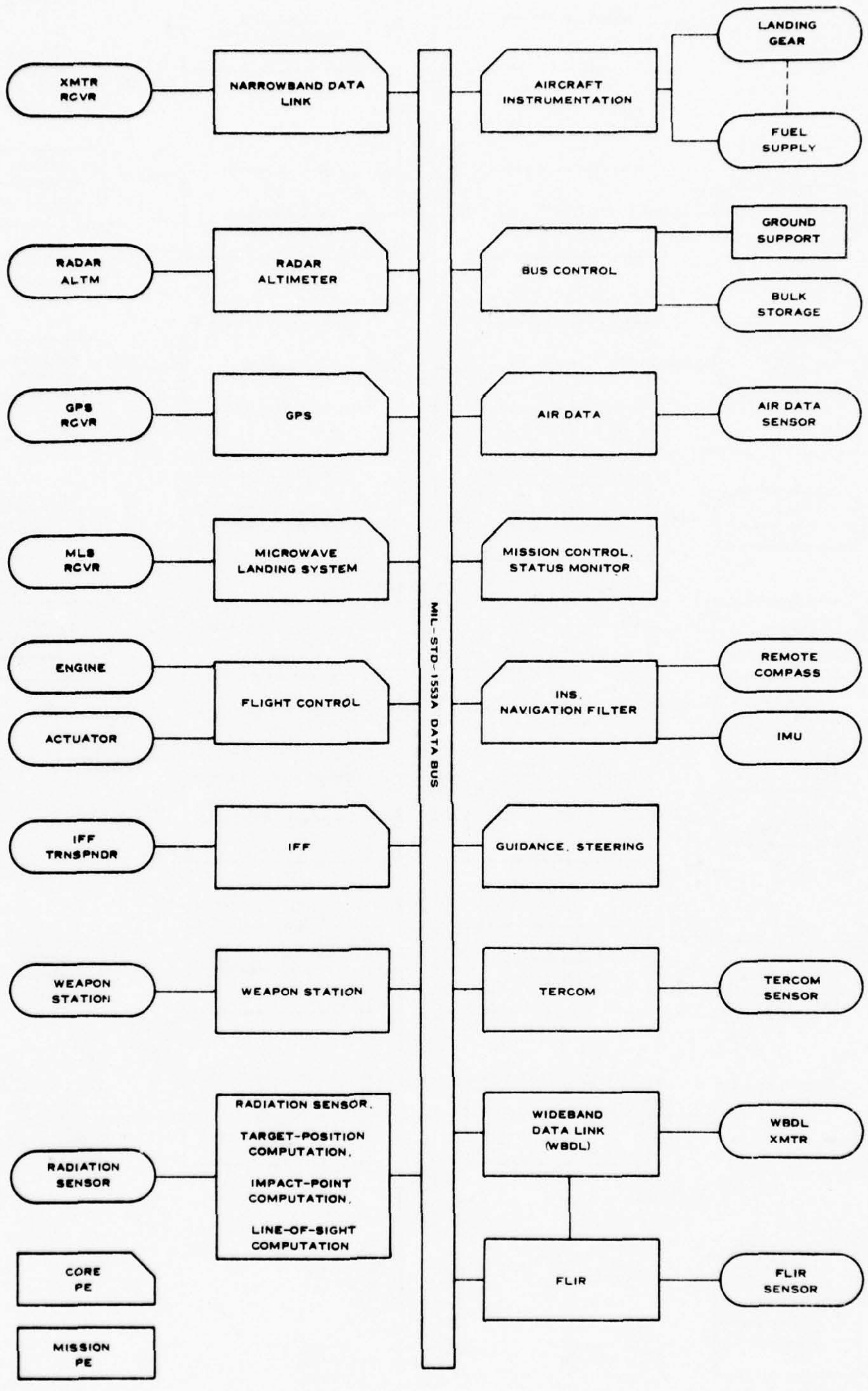


Figure 15. DP/M System–Strike Configuration

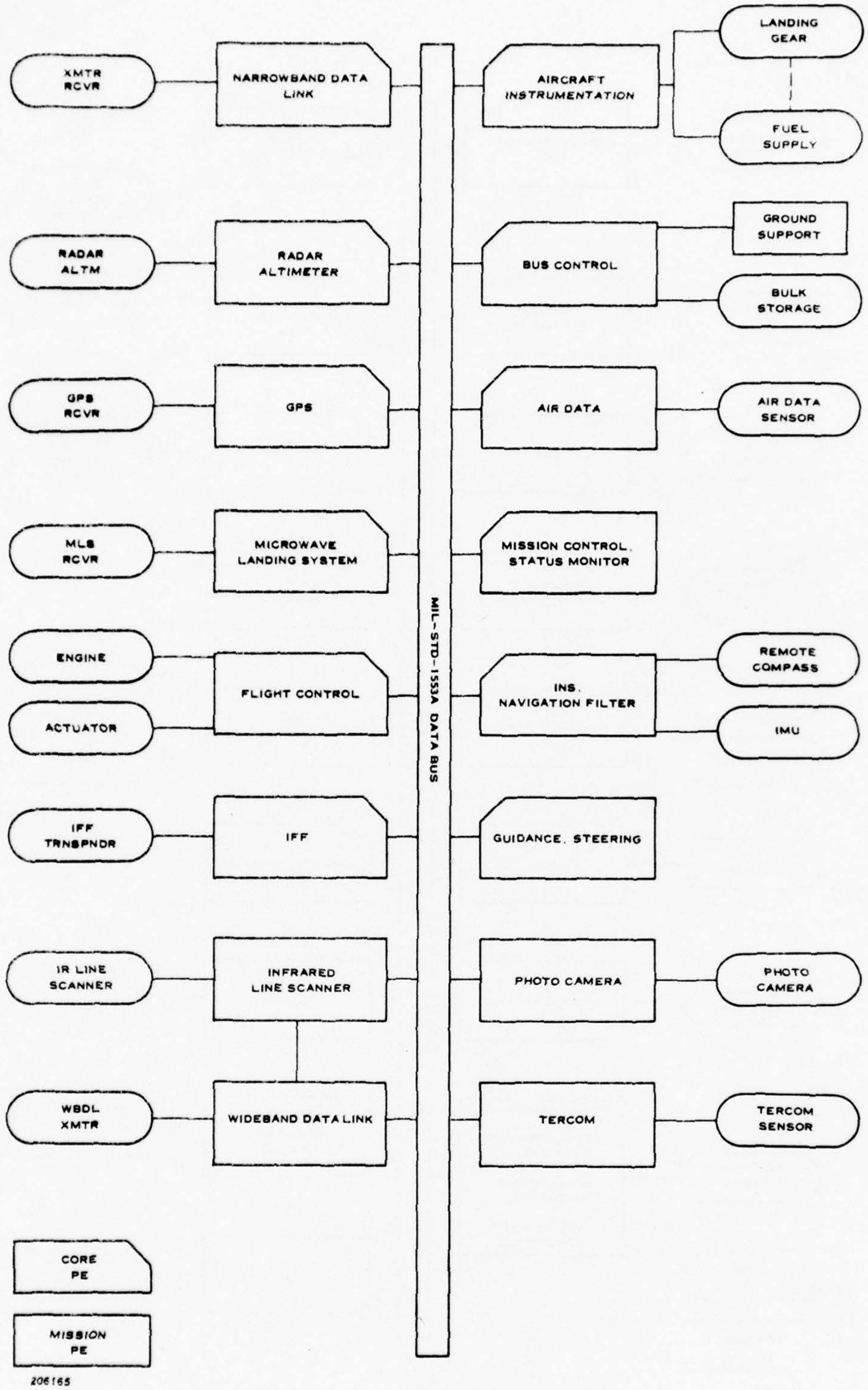


Figure 16. DP/M System–Recce Configuration

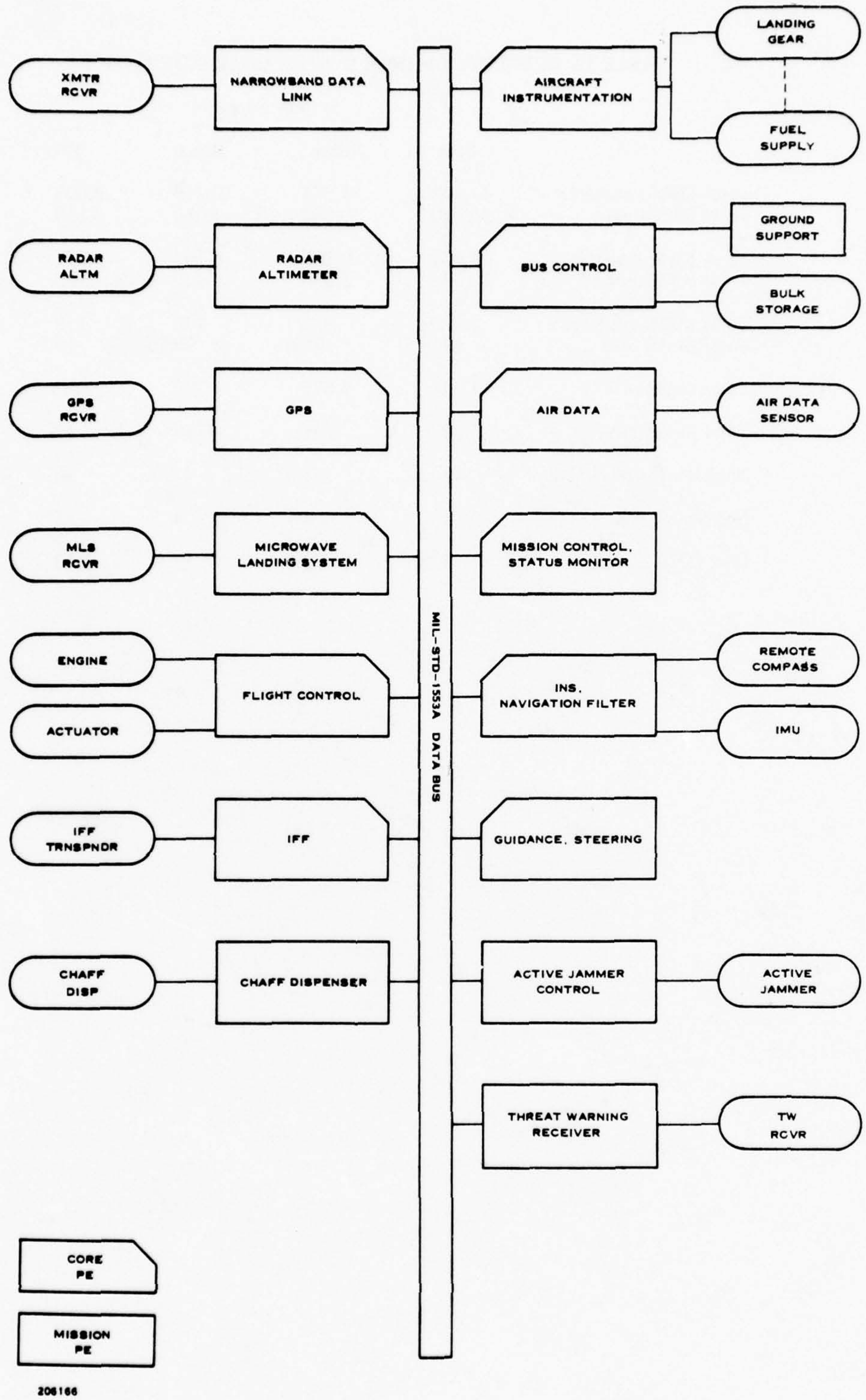


Figure 17. DP/M System—EW Configuration

TABLE 16. SUMMARY OF DP/M SYSTEM CHARACTERISTICS

	System Function			
	Core	Strike	Recce	EW
Total PROM available	47,104	15,872	10,240	4,608
Total PROM used	34,010	9,290	5,060	3,110
Total RAM available	28,672	9,216	8,192	3,072
Total RAM used	12,335	3,290	2,470	600
Total KOPS available	2,220	925	740	555
Total KOPS used	325.85	175.45	79.75	10.5
Total volume (in^3)	4,200	1,675	1,340	1,005
Total power (watts)	367	148	117	81
Total weight (pounds)	124.5	51.5	41	30
Number of PEs	12	5	4	3
Cost ($K)	52.6	21.9	17.5	13.2

TABLE 17. DP/M SYSTEM PE CHARACTERISTICS

Processing Element	PROM Available	PROM Used	RAM Available	RAM Used	KOPS Available	KOPS Used	Power (watts)	Weight (pounds)
CORE								
Communications	1,536	1,050	1,024	580	185	3.3	27	10
Instrumentation	1,536	570	1,024	110	185	0.55	27	10
Altimeter	1,536	650	1,024	110	185	0.55	27	10
Bus Control	1,536	1,050	5,120	2,100	185	30	32	10.5
GPS	13,824	12,000	5,120	2,180	185	74.8	45	12
MLS	1,536	1,160	1,024	180	185	8.5	27	10
INS	5,632	4,800	5,120	2,960	185	110	36	11
Flight Control	5,632	3,250	1,024	680	185	50	31	10.5
Guidance	5,632	3,420	1,024	510	185	21	28	10
IFF	1,536	650	1,024	110	185	0.55	27	10
Mission Control	5,632	4,350	5,120	2,660	185	20	33	10.5
Air Data	1,536	1,060	1,024	155	185	6.6	27	10
STRIKE								
Weapon Station	1,536	1,050	1,024	180	185	3.3	27	10
FLIR	1,536	1,100	1,024	180	185	3.3	27	10
WBDL	1,536	670	1,024	130	185	0.55	27	10
Weapon Delivery	5,632	3,520	1,024	720	185	91.3	31	10.5
TERCOM	5,632	2,950	5,120	2,080	185	77	36	11
RECCE								
IR Scanner	1,536	720	1,024	130	185	1.1	27	10
WBDL	1,536	670	1,024	130	185	0.55	27	10
TERCOM	5,632	2,950	5,120	2,080	185	77	36	11
Camera	1,536	720	1,024	130	185	1.1	27	10
EW								
Jammer	1,536	1,380	1,024	280	185	7.7	27	10
Threat Warning	1,536	900	1,024	180	185	1.7	27	10
Chaff Dispensing	1,536	830	1,024	140	185	1.1	27	10

TABLE 18. TASK ASSIGNMENT FOR DP/M CORE AVIONICS

Processing Element	Tasks Assigned	Modules Per PE					
		SBIM	IOIM	MPM	PMM	DMM	VRM
Communications	Narrowband Data Link Subsystem Service	1	1	1	0	0	1
Instrumentation	Aircraft Instrumentation	1	1	1	0	0	1
Altimeter	Radar Altimeter Subsystem Service	1	1	1	0	0	1
Bus Control	Bus Control, Bulk Storage Subsystem Service	1	1	1	0	1	1
GPS	GPS	1	1	1	3	1	1
MLS	Microwave Landing System	1	1	1	0	0	1
INS	INS, Navigation Filter	1	1	1	1	1	1
Flight Control	Flight Control	1	1	1	1	0	1
Guidance	Guidance, Steering	1	1	1	1	0	1
IFF	IFF Subsystem Service	1	1	1	0	0	1
Mission Control	Mission Control, Status Monitor	1	0	1	1	1	1
Air Data	Air Data	1	1	1	0	0	1

TABLE 19. TASK ASSIGNMENT FOR DP/M STRIKE AVIONICS

Processing Element	Tasks Assigned	Modules Per PE					
		SBIM	IOIM	MPM	PMM	DMM	VRM
Weapon Station	Weapon Station Subsystem Service	1	1	1	0	0	1
Weapon Delivery	Line-of-Sight Computation, Radiation Sensor Subsystem Service, Target Position Computation, Impact Point Computation	1	1	1	1	0	1
TERCOM	TERCOM	1	1	1	1	1	1
FLIR	FLIR Subsystem Service	1	1	1	0	0	1
Wideband Data Link	Wideband Data Link Subsystem Service	1	1	1	0	0	1

TABLE 20. TASK ASSIGNMENT FOR DP/M RECCE AVIONICS

Processing Element	Tasks Assigned	SBIM	IOIM	Modules Per PE MPM	PMM	DMM	VRM
IR Scanner	IR Line Scanner Subsystem Service	1	1	1	0	0	1
WBDL	Wideband Data Link Subsystem	1	1	1	0	0	1
TERCOM	TERCOM	1	1	1	1	1	1
Camera	Photo Camera Subsystem Service	1	1	1	0	0	1

TABLE 21. TASK ASSIGNMENT FOR DP/M EW AVIONICS

Processing Element	Tasks Assigned	SBIM	IOIM	Modules Per PE MPM	PMM	DMM	VRM
Jammer	Active Jammer Control	1	1	1	0	0	1
Threat Warning	Threat Warning Receiver Subsystem Service	1	1	1	0	0	1
Chaff Dispenser	Chaff Dispenser Subsystem Service	1	1	1	0	0	1

D. HYBRID SYSTEM

In the Hybrid system, the total ARPV processing problem is partitioned by major functional area. ARPV subsystems and processing tasks which are functionally related are grouped together and assigned to individual PEs.

Block diagrams of the Hybrid system are shown in Figure 18 through Figure 20 for the three mission configurations. A summary of the Hybrid system characteristics is shown in Table 22. Characteristics of individual PEs within the Hybrid system are shown in Table 23. Task assignments and module complement for core and mission-specific PEs are shown in Tables 24 through 27.

Utilization of processing resources within the Hybrid system is shown below:

	Percent Utilization		
Hybrid Network	**PROM Memory**	**RAM Memory**	**Throughput**
Core	81.8	54.7	29.3
Strike	58.5	35.7	18.9
Recce	52.4	34.5	14.4
EW	36.4	29.3	2.9

This table indicates that the Hybrid system resources are utilized slightly more efficiently than in the DP/M case described previously. As in the DP/M system, there is ample margin for growth in the Hybrid system. Also PROM or RAM can be added to existing PEs and the system can be expanded by adding new PEs.

Peak bus traffic for segment 8 of the strike mission is summarized below for the Hybrid strike configuration:

Total traffic	93.90 kbps
Traffic utilized for data	49.80 kbps (53.03 percent)
Traffic utilized for header	39.20 kbps (41.75 percent)
Traffic utilized for gap	4.90 kbps (5.22 percent)

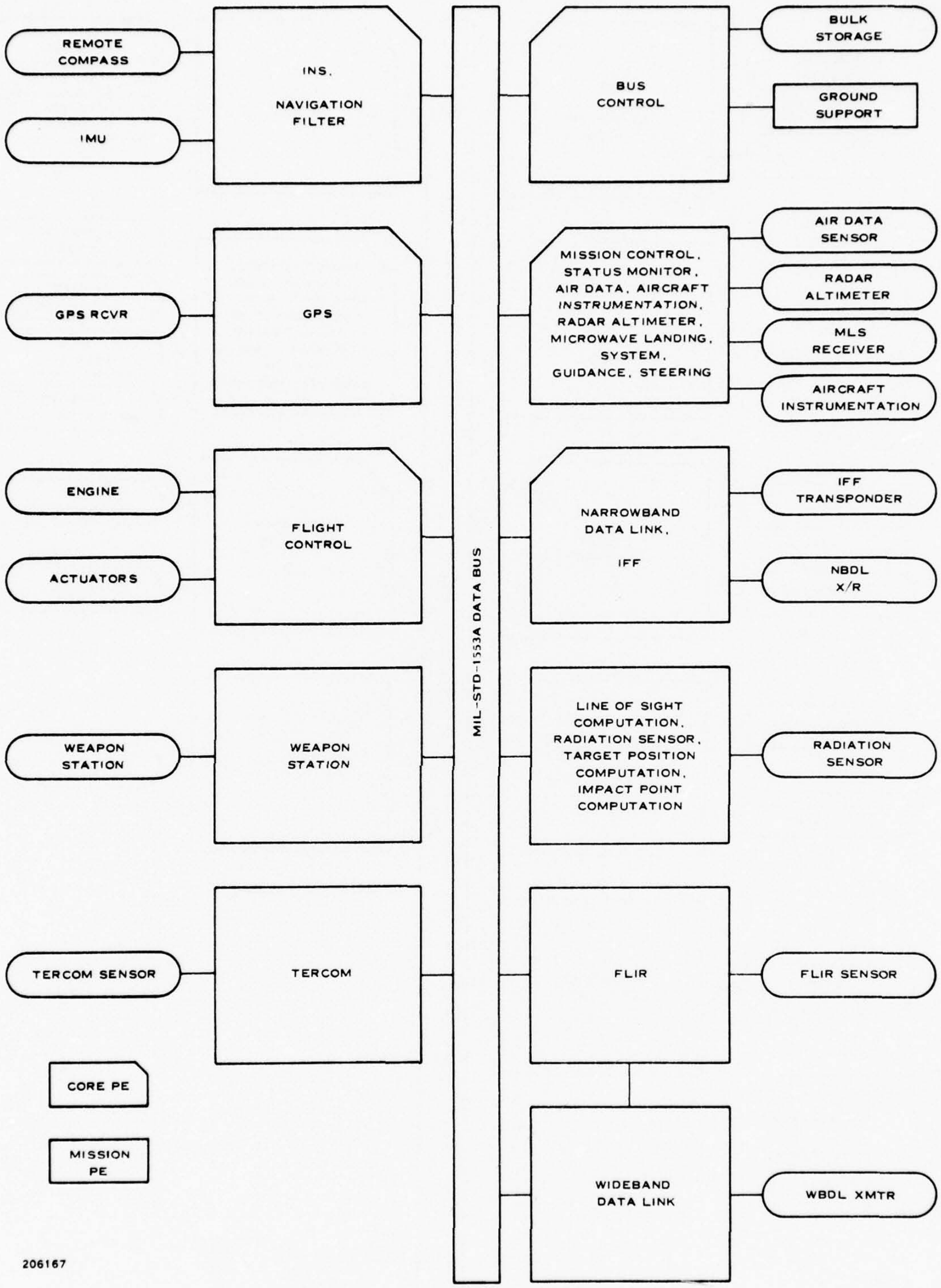


Figure 18. Hybrid System–Strike Configuration

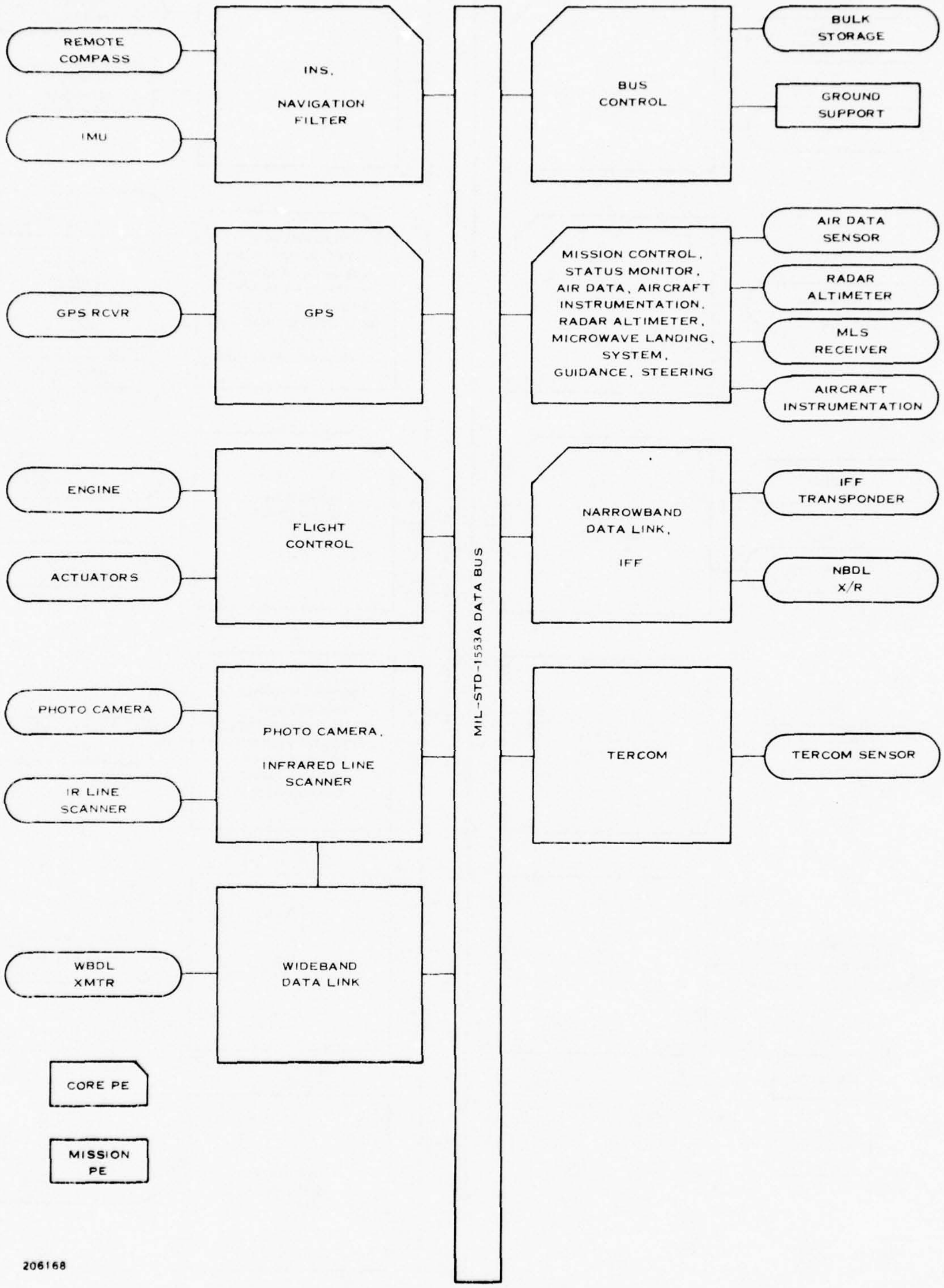


Figure 19. Hybrid System–Reece Configuration

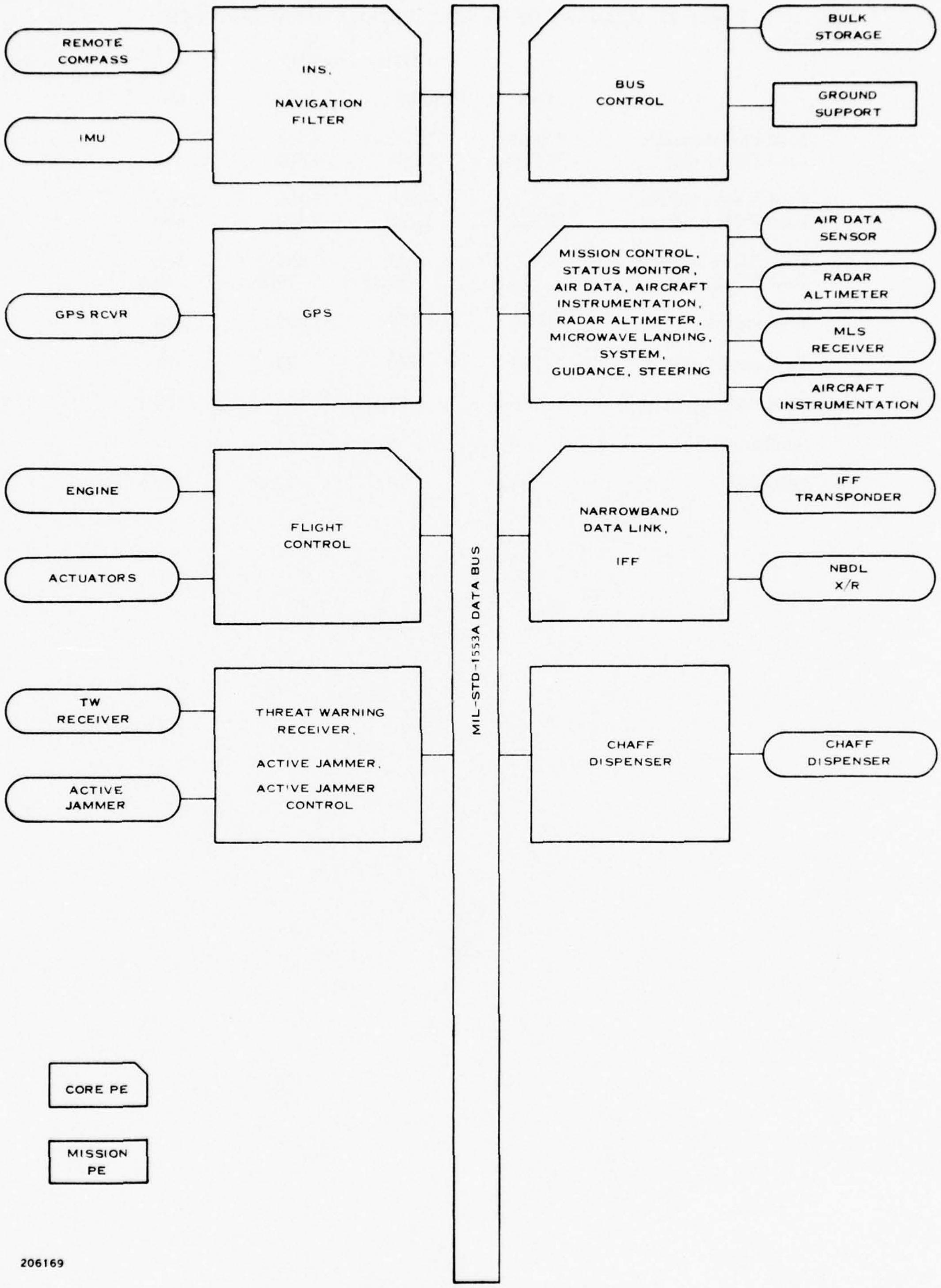


Figure 20. Hybrid System–EW Configuration

TABLE 22. SUMMARY OF HYBRID SYSTEM CHARACTERISTICS

	System Function			
	Core	Strike	Recce	EW
Total PROM available	37,888	15,872	8,704	7,168
Total PROM used	31,010	9,290	4,560	2,610
Total RAM available	22,528	9,216	7,168	2,048
Total RAM used	12,325	3,290	2,470	600
Total KOPS available	1,110	925	555	370
Total KOPS used	324.8	175.45	79.75	10.6
Total volume (in^3)	2,010	1,675	1,005	670
Total power (watts)	211	148	90	58
Total weight (pounds)	65.5	51.5	31	20.5
Number of PEs	6	5	3	2
Cost ($K)	34.8	29.0	17.4	11.6

TABLE 23. HYBRID SYSTEM PE CHARACTERISTICS

Processing Element	PROM Available	PROM Used	RAM Available	RAM Used	KOPS Available	KOPS Used	Power (watts)	Weight (pounds)
CORE								
INS	5,632	4,800	5,120	2,960	185	110	36	11
GPS	13,824	12,000	5,120	2,180	185	74.8	45	12
Flight Control	5,632	3,250	1,024	680	185	50	31	10.5
Bus Control	1,536	1,050	5,120	2,100	185	30	32	10.5
Mission Control	9,728	8,710	5,120	3,725	185	56	40	11.5
Communications	1,536	1,200	1,024	680	185	4	27	10
STRIKE								
Weapon Station	1,536	1,050	1,024	180	185	3.3	27	10
Weapon Delivery	5,632	3,520	1,024	720	185	91.3	31	10.5
TERCOM	5,632	2,950	5,120	2,080	185	77	36	11
FLIR	1,536	1,100	1,024	180	185	3.3	27	10
WBDL	1,536	670	1,024	130	185	0.55	27	10
RECCE								
Imagery	1,536	940	1,024	260	185	2.2	27	10
WBDL	1,536	670	1,024	130	185	0.55	27	10
TERCOM	5,632	2,950	5,120	2,080	185	77	36	11
EW								
ECM	5,632	1,780	1,024	460	185	9.5	31	10.5
Chaff Dispenser	1,536	830	1,024	140	185	1.1	27	10

TABLE 24. TASK ASSIGNMENT FOR HYBRID CORE AVIONICS

Processing Element	Tasks Assigned	Modules Per PE					
		SBIM	IOIM	MPM	PMM	DMM	VRM
INS	Strapdown Inertial Navigation, Navigation Filter	1	1	1	1	1	1
GPS	Global Positioning Navigation Update	1	1	1	3	1	1
Flight Control	Stabilization and Command Control, Engine Control	1	1	1	1	0	1
Bus Control	Serial Data Bus Control (MIL-STD-1553A) Bulk Storage Subsystem Service	1	1	1	0	1	1
Mission Control	Mission Control, Status Monitor, Air Data, Aircraft Instrumentation, Radar Altimeter, Microwave Landing System, Guidance, Steering	1	1	1	2	1	1
Communications	Narrowband Data Link Subsystem Service, IFF Subsystem Service	1	1	1	0	0	1

TABLE 25. TASK ASSIGNMENT FOR HYBRID STRIKE AVIONICS

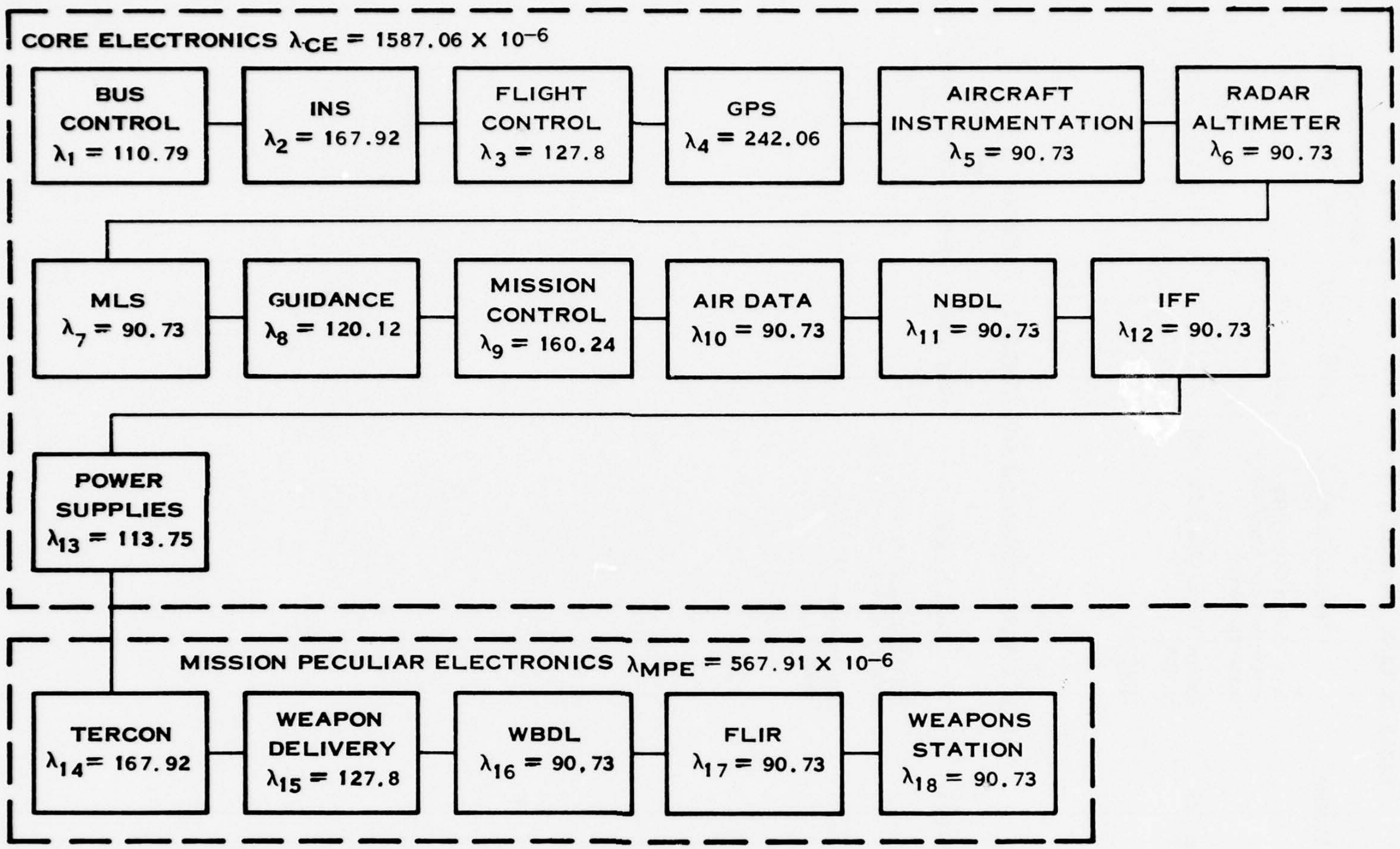
Processing Element	Tasks Assigned	Modules Per PE					
		SBIM	IOIM	MPM	PMM	DMM	VRM
Weapon Station	Weapon Station Subsystem Service	1	1	1	0	0	1
Weapon Delivery	Line-of-Sight Computation, Radiation Sensor Subsystem Service, Target Position Computation, Impact Point Computation	1	1	1	1	0	1
TERCOM	TERCOM	1	1	1	1	1	1
FLIR	FLIR Subsystem Service	1	1	1	0	0	1
Wideband Data Link	Wideband Data Link Subsystem Service	1	1	1	0	0	1

TABLE 26. TASK ASSIGNMENT FOR HYBRID RECCE AVIONICS

Processing Element	Tasks Assigned	Modules Per PE SBIM	IOIM	MPM	PMM	DMM	VRM
Imagery	Photo Camera Subsystem Service, Infrared Line Scanner Subsystem Service	1	1	1	0	0	1
Wideband Data Link	Wideband Data Link Subsystem Service	1	1	1	0	0	1
TERCOM	TERCOM	1	1	1	1	1	1

TABLE 27. TASK ASSIGNMENT FOR HYBRID EW AVIONICS

Processing Element	Tasks Assigned	Modules Per PE SBIM	IOIM	MPM	PMM	DMM	VRM
ECM	Threat Warning Subsystem Service, Active Jammer Control	1	1	1	1	0	1
Chaff Dispenser	Chaff Dispenser Subsystem Service	1	1	1	0	0	1



$$\lambda_T = \sum_{i=1}^{13} \lambda_i + \sum_{i=14}^{18} \lambda_j = 1587.06 \times 10^{-6} + 567.91 \times 10^{-6} = 2154.97 \times 10^{-6}, \quad \text{MTBF} = \frac{1}{\lambda_T} = 464.04 \text{ HOURS}$$

206170

Figure 21. Reliability Prediction for DP/M System–Strike Configuration

E. RELIABILITY ANALYSIS

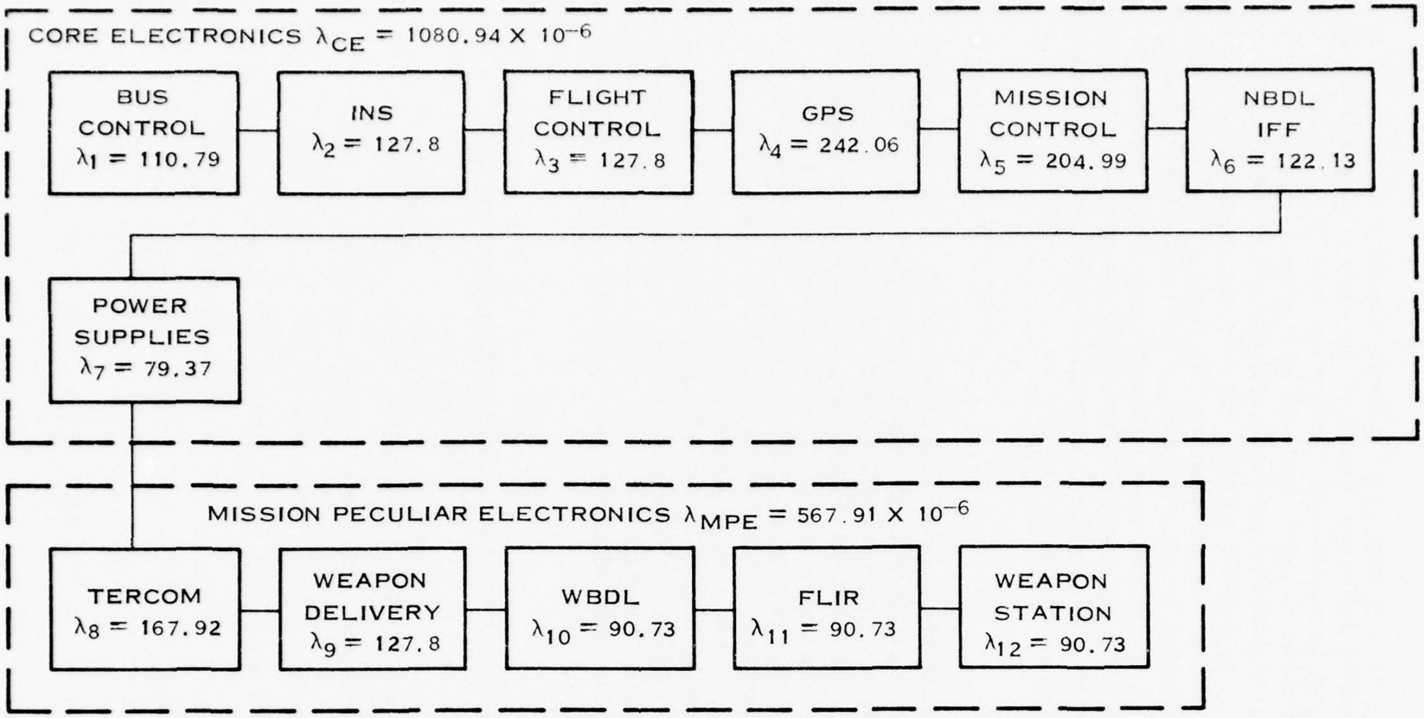
A detailed reliability study was performed to aid in determining the optimum digital avionic system for the multimission ARPV application. Results of the study indicate that the Hybrid system is the most attractive both from a hardware reliability standpoint (in particular for safety of flight) and also from the increased reliability due to the low-complexity software used in this type of architecture. Because the structuredness and low-complexity software attributes of the Hybrid system make it easy to understand, maintain and alter, the overall reliability of this system should be primarily a function of the hardware. The primary result of the reliability study is the prediction of a minimum hardware reliability of 607 hours MTBF for any mission configuration of the Hybrid system. The corresponding operational reliability based on a 1-hour mission is 0.998. The following paragraphs describe the methods and assumptions used in making the hardware reliability predictions and the results of these predictions. In addition, a description of some of the software reliability considerations is given.

1. Hardware Reliability

Results of the hardware reliability predictions are shown in Table 28 for the three different processing systems (DP/M, Hybrid and Centralized) considered. As shown in Table 28, both total serial and mission-success predictions were performed for all three mission configurations (Strike, Recce and EW) of each system. Aircraft safety of flight predictions also were performed for each of the core systems. The total serial or total system predictions are indicative of the reliability of the various system configurations assuming any failure is critical, e.g., from a maintenance standpoint. For the mission-critical or mission-success predictions, only those parts and assemblies were considered which could cause a given mission to be unsuccessful if they failed. Likewise, for the flight-critical or aircraft safety-of-flight predictions only those assemblies affecting flight safety were considered. A detailed prediction chart for each case shown in Table 28 is included in Appendix E. For illustrative purposes, Figures 21 through 23 are included here to show block diagrams of the most complex mission configurations (strike mission) for the three different systems considered.

TABLE 28. MTBF SUMMARY FOR ARPV AVIONICS PROCESSING SYSTEMS

	MTBF (hours)					
	DP/M		Hybrid		Centralized	
Reliability Model	45°C	80°C	45°C	80°C	45°C	80°C
Strike Mission (Total Serial)	729	464	962	607	1,001	718
Strike Mission (Success)	928	588	1,084	682	1,104	797
Recce Mission (Total Serial)	775	493	1,110	699	1,104	797
Recce Mission (Success)	1,019	646	1,110	699	1,164	843
EW Mission (Total Serial)	842	538	1,221	770	1,104	797
EW Mission (Success)	1,129	717	1,353	854	1,230	894
Aircraft Safety of Flight	1,586	1,018	1,874	1,192	1,485	1,096



$$\lambda_T = \lambda_{CE} + \lambda_{MPE} = \sum_{i=1}^{7} \lambda_i + \sum_{j=8}^{12} \lambda_j = 1080.94 \times 10^{-6} + 567.91 \times 10^{-6}$$

$$MTBF = \frac{1}{\lambda_T} = 606.5 \text{ HOURS}$$

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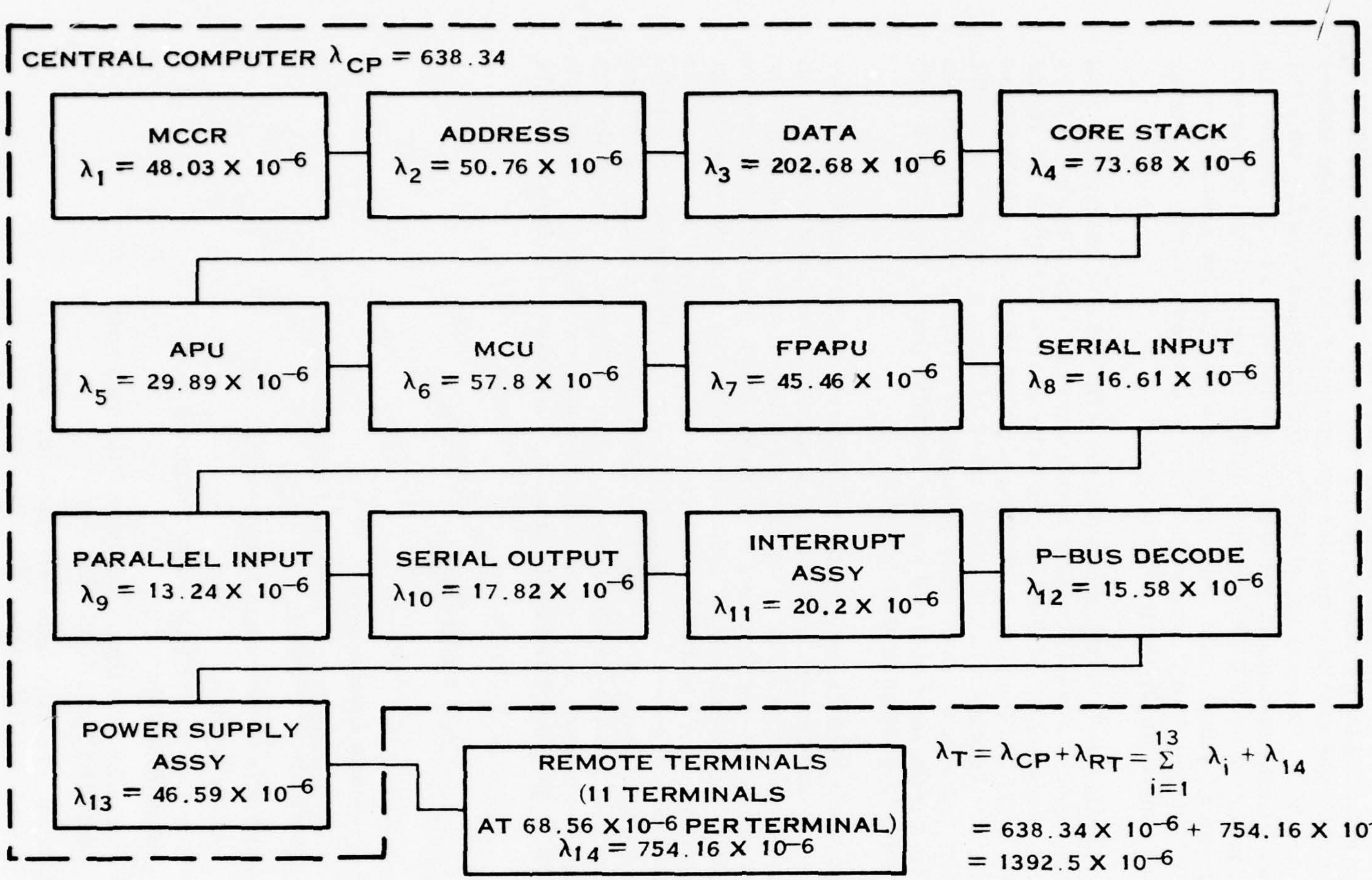
Figure 22. Reliability Prediction for Hybrid System–Strike Configuration



$$\lambda_T = \lambda_{CP} + \lambda_{RT} = \sum_{i=1}^{13} \lambda_i + \lambda_{14}$$

$$= 638.34 \times 10^{-6} + 754.16 \times 10^{-6}$$

$$= 1392.5 \times 10^{-6}$$

$$\mathrm{MTBF} = \frac{1}{\lambda_T} = 718 \text{ HOURS}$$

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Figure 23. Reliability Prediction for Centralized System–Strike Configuration

Failure rates used in making the reliability predictions were obtained from MIL-HDBK-217B and Texas Instruments data using airborne uninhabited environmental K factors and part ambient temperatures of 45° and 80°C. Maximum use of JANTX and established reliability parts and mature microelectronic devices (purchased to MIL-M-38510 specifications) was also assumed. All predictions were first performed at 80°C (70°C ambient + 10°C assumed heat rise) to determine the reliability of the various systems under worst case conditions. Then the predictions were performed at 45°C (35° ambient + 10°C assumed heat rise) to illustrate the effect of operating the system at a reduced temperature by means of cooling air.

The reliability predictions of Table 28 indicate that the MTBFs at 80°C are higher in most cases for the Centralized system. The MTBFs of the Hybrid system are approximately 100 hours less in all cases except aircraft safety of flight. In this latter case, the MTBF of the Hybrid system is considerably higher due to natural partitioning of system operations along functional lines. That is, much of the circuitry affecting aircraft safety of flight is independent for the Hybrid system. In every case except aircraft safety of flight, the MTBF of the DP/M system is lower than that of the Hybrid and Centralized systems, primarily due to the increased parts count resulting from complete partitioning along task lines.

As shown by the data in Table 28, reducing the temperature from 80° to 45°C significantly improves the MTBF of all configurations considered. It is especially interesting to note that this reduction in temperature allows the MTBF of the Hybrid system to almost equal that of the Centralized system in some cases and to exceed it in others. At this point, it is important to remember that the DP/M and Hybrid systems utilize high complexity microelectronic devices (i.e., ROMS, microprocessors, etc.) which allow considerable reduction in total parts count. The Centralized system primarily utilizes relatively low complexity devices. At the present time (refer to MIL-HDBK-217B) the failure rates of the high complexity integrated circuits are much larger at a given temperature than low complexity devices. In addition the failure rates of the high complexity devices vary more rapidly for a given change in temperature. The following example using MIL-HDBK-217B is given to illustrate this situation. The failure rate equation for the example is:

$$\lambda_p = \pi_L \, \pi_Q \, (C_1 \, \pi_{T_1} + C_2 \, \pi_E)$$

where

λ_p = device failure rate in $F/10^6$

π_L = device learning factor determined from table 2.1.5-1 of MIL-HDBK-217B

π_Q = quality factor determined from table 2.1.5-1 of MIL-HDBK-217B

π_{T_1} = temperature acceleration factor determined from MIL-HDBK-217B

π_E = application environment multiplier determined from table 2.1.5-3 of MIL-HDBK-217B

C_1, C_2 = circuit complexity factors determined from table 2.1.5-5 of MIL-HDBK-217B for low complexity digital devices and from table 2.1.5-8 of MIL-HDBK-217B for memory devices.

Device Type	Assumptions	Calculations
4096-bit ROM	Part Ambient Temperature = 80°C	$\lambda_p = (1.0)(2)[(0.17)(3.6)+(0.07)(6)]$
	T_j = 110°C	= 2.064
4096-bit ROM	Part Ambient Temperature = 45°C	$\lambda_p = (1.0)(2)[(0.17)(1.0)+(0.07)(6)]$
	T_j = 75°C	= 1.18
Typical TTL Device	Part Ambient Temperature = 80°C	$\lambda_p = (1.0)(2)[(0.0061)(1.8)+(0.0089)(6)]$
(10-gate complexity)	T_j = 90°C	= 0.129
Typical TTL Device	Part Ambient Temperature = 45°C	$\lambda_p = (1.0)(2)[0.0061)(0.44)+(0.0089)(6)]$
(10-gate complexity)	T_j = 55°C	= 0.112

For the 4096-bit ROM, the ratio of the failure rate of 80°C to that at 45°C is 1.75 (= 2.064/1.18) while the corresponding ratio for the typical TTL device of 10-gate complexity is 1.15 (= 0.129/0.112). This illustrates that the relative change in failure rate resulting from temperature changes is much greater for the higher complexity devices than for the lower complexity devices. Observation of the above calculations indicates that the failure rate of the higher complexity devices is not only greatly influenced by the increased complexity but also greatly affected by the higher junction temperatures resulting from higher levels of power dissipation. It should be noted that the relatively high failure rate of the high-complexity devices is often offset by the composite failure rate of the large number of low-complexity devices which they replace. That is, use of low-complexity devices to perform the same function as that of a microprocessor or other high-complexity device would not only greatly increase the overall parts count, cost, and packaging space but would also increase the overall failure rate since the failure rate of the higher complexity devices is generally less than the combined failure rate of the lower complexity devices required to perform the same function.

Considering the tradeoff factors of reliability, cost, ease of testing and overall flexibility, the Hybrid system appears to be the most attractive. From a pure reliability standpoint, the MTBF of the Hybrid system is very close to that of the Centralized system for some cases and actually higher for other cases. The aircraft safety-of-flight MTBF for the Hybrid system greatly exceeds that of the Centralized system because the circuitry associated with aircraft safety of flight for the Hybrid system is independent of most of the other circuitry. This circuitry independence does not exist for the Centralized system. Because of the relatively high MTBFs that are achievable for the Hybrid system, redundancy was not considered necessary at this time. The lowest predicted MTBF for the Hybrid system was 607 hours for the strike mission under worst case conditions. Although no redundancy was considered at this time, implementation of redundancy for the Hybrid system is much easier and more cost effective than for the Centralized case. In the case of the DP/M system, the added flexibility resulting from complete partitioning along task lines does not appear to be sufficient to offset its higher cost and lower reliability resulting from the use of a much larger number of modules.

TABLE 29. SOFTWARE RELIABILITY SOURCES

Title	Author	Source
Software Reliability: Measurement Models	Martin L. Shooman	Proceedings 1975 Annual Reliability and Maintainability Symposium
Embedded Computer System Software Reliability	Lt. Col. John H. Manley, USAF	*Defense Management Journal*, Vol. II, No. 4, October, 1975
Testing Strategies for Software Reliability Assessment	John R. Brown Advanced Defense Systems TRW Systems Redondo Beach, California	Prepared for the Joint Logistics Commander's Electronics Systems Reliability Workshop May, 1975
Special Report for the SRWG on the International Conference on Reliable Software	Peter Wegner Brown University Providence, Rhode Island	Prepared for the Joint Logistics Commander's Electronics Systems Reliability Workshop June, 1975
Software Reliability–How It Affects System Reliability	James A. Ronback CAE Electronics Ltd. Montreal	*Microelectronics and Reliability*, Vol. 14, pages 121-140.

2. Software Reliability

As part of the reliability study, many articles on software reliability were reviewed. A list of these articles and their authors is included in Table 29. Software reliability is defined as the probability that the software will satisfy the stated operational requirements for a specified time interval or a unit application in the operational environment. It has been stated that the complexity of investigating software reliability problems undoubtedly has discouraged academic research, as witnessed by the lack of literature on the subject, since clear-cut conclusions are nearly impossible to derive from field experimentation on deployable systems. Some of the primary causes of computer software failures are (1) design and coding errors and (2) externally caused failures such as computer hardware failures, interactions with other system components, incorrect human inputs and environmental changes. In addition, some of the software characteristics which make reliability determinations difficult are:

Software interfaces are conceptual rather than physical (there is no easy-to-visualize three-prong plug and its mate)

There are many more distinct paths to check in software than in hardware

There are many more distinct entities to check (any item in a large file may be a source of error)

Software errors generally come with no advance warning, provide no period of graceful degradation, and, more often, provide no announcement of their occurrence.

Many system failures are created due to complexity alone. As in the case of hardware, the structure of software may evolve into a system which is difficult to understand, hard to maintain and hazardous to alter because many parts of the system are so tightly coupled to each other. As indicated previously in this report, studies prior to this ARPV study have shown that the digital data processing associated with the avionics tasks can be easily partitioned into a number of simpler tasks. This fact tends to simplify software for the case of a distributed network. Also, the executive software can be table driven, which makes it flexible and provides for separation of system logic and application software modules. The structuredness and lower complexity attributes of the DP/M and Hybrid systems make them easier to understand, maintain and alter. Thus, they can be implemented faster, be checked out more thoroughly, and provide higher reliability. The major contribution that is made toward system reliability is the testability of a well-structured software design which can be achieved in a distributed processing system.

The tests required for each software module are easier to design and thus can be made more thorough. The thoroughness of the testing performed can be monitored and accepted with more confidence. With unstructured software systems, determining the completeness of the testing that is done is difficult and this is what has conditioned people to expect a large number of bugs in software. Use of heirarchically modular system software is a necessity for the discovery of design errors early in the design cycle and for prevention of many error types altogether. Also heirarchical modularity promotes highly localized error/change effects so that software modules can be modified without introducing errors or affecting other modules.

Another factor influencing software reliability is the type of programming language selected. Use of higher order languages results in programming flexibility, operational reliability, maintainability, and lower development risk associated with software handover to new programmers, reduced training problems, software commonality, etc. However, all the factors which affect the tradeoff of HOL versus AL must be considered since there is no universally firm answer to this trade as yet.

The software reliability features along with the hardware reliability achievable make the Hybrid system highly attractive from a reliability standpoint.

F. MAINTAINABILITY ANALYSIS

In preparing data for input to the LCC analysis, several assumptions and considerations had to be made in the absence of firm data. Those considerations pertaining to the operation and maintenance of the system are discussed in this subsection.

1. Assumptions

The entire complement of aircraft was considered to be equally distributed between three locations. The equipment was to remain essentially in storage throughout the entire 10-year anticipated lifetime. Each of the locations was considered to fly each equipment for 1 hour each year or approximately four flights per week average. This effort was intended to maintain skills as well as keep a check on the status of the equipment.

Test equipment assumptions included programming/testing equipment at each organizational level, testing equipment for intermediate maintenance at each location plus one at some central location for preparing, evaluation, and refinement of testing procedures and programs, and one central depot test set. This required three sets of organizational level equipment, four sets of intermediate level equipment, and one set of depot equipment.

The operational maintenance concept used in the study assumed the aircraft would be removed from storage and moved to a flight preparation area. The aircraft would be fueled, stores loaded, a built-in test (BIT) performed on the electronics, the mission-specific requirements programmed in, and the aircraft removed to the launch area. After recovery, the aircraft would be down-loaded, a BIT performed, and the aircraft prepared for storage or reconfigured for the next mission. At any time a malfunction is detected during built-in testing or programming, the defective unit will be isolated using the built-in test or the test equipment associated with the programming equipment. The defective unit would be removed and replaced by a unit from stock. The defective unit would be tested in the intermediate shop, the defective module isolated, removed, and replaced, and the unit tested and returned to supply. The defective module would be returned to depot for testing, fault isolation, and repair based on a code supplied by a detailed repair level study performed on each module. This detailed level-of-repair study would be a part of the overall system design program.

The total operating time per sortie on the equipment including the flying time, self-test time, and programming time was assumed to be approximately 1.5 hours. (This comprises 1 hour flying, 5 minutes total self-test before and after flight, and 25 minutes programming time.)

The MTBMA was determined by a "K" factor applied to the MTBF. The "K" factor is determined by the knowledge that the system will not reach its mature failure rate by the design freeze point in a production program. Field history as well as calculations show that the appropriate factor will be approximately 0.2 with approximately 25 percent of these maintenance actions resulting in no repair action requiring intermediate-level maintenance. The "K" factors used, then, are MTBMA = 0.2 MTBF and the maintenance actions requiring intermediate maintenance activity = 0.25 MTBF.

For purposes of this program, the quantity of maintenance actions allowing a throwaway concept at the intermediate level must be minimized due to the scope of a study required to analyze each module individually after design. This throwaway decision is dependent on the cost of the printed wiring boards. Preliminary review of the PWB design and cost data indicates that approximately 20 to 30 percent of the PWBs may be discarded rather than repaired. These numbers were used in the LCC calculations.

The number of people associated with maintenance was calculated based on the assumption of one man trained at depot for module repair and eight per site, comprising one supervisor, three organizational and four intermediate people. Less than 100 percent utilization of personnel on this equipment was determined, but the loading was designed for the ARPV system to become fully operational on a 24-hour basis in order to fly combat missions. For daily operation, three people would be expected to perform other duties as a three-shift operation is unlikely.

These assumptions were made to simulate the most likely activity to be experienced by the equipments. Except where differences in the candidate systems caused a difference in the assumptions, identical values were used in each of the three systems analyzed.

2. Analysis Results

Mean-time-to-repair predictions were made on each system at all maintenance levels. The organizational level prediction assumes a second man during the 0.1-hour period of physically removing and replacing the central computer on the Centralized system. The second man is not required for the DP/M or Hybrid systems nor for the intermediate and depot levels.

Level	Centralized (man-hours)	Hybrid (man-hours)	DP/M (man-hours)
Organizational	0.5	0.25	0.25
Intermediate	1.0	0.5	0.5
Depot	0.8	0.8	0.8

The significant difference in the organizational level prediction is the weight of the units. Fault isolation will be essentially the same, as will the programming and testing. The numerous small units of the distributed networks make those systems much easier to repair.

The significant difference in the intermediate level prediction is the ease of testing, fault isolation, and location of the defective modules. Again, the smaller units have advantages over the centralized computer due to similarity of the units.

The depot level maintenance prediction was taken from recent demonstrations of similar complexity. No significant difference between the systems was anticipated at this level, so the repair times are identical.

SECTION IV
COST-OF-OWNERSHIP ANALYSIS

A. DEFINITION OF OPERATIONAL/MAINTENANCE CONSIDERATIONS

1. General

The life-cycle cost model for the ARPV processing system is but one of the elements in the overall LCC analysis flow as shown in Figure 24. Very essential driving elements precede or accompany the cost model. These principal drivers are doctrines, ARPV system characteristics, and standard USAF cost factors.

As seen in Figure 24, the procurement aspects of the ARPV will dictate the number of ARPV vehicles which will eventually be available. The operational life-cycle scenario is postulated from the number of ARPV vehicles purchased and the mission requirements; i.e., the total number of operating hours for the ARPV is the result of multiplying the number of ARPVs by the number of average flying hours per ARPV mission. When the number of operating hours is combined with the overall ARPV system characteristics, maintenance and support concepts are determined. These factors are then introduced into the ARPV processing system LCC model.

Standard USAF cost factors, which are available in the areas of labor rates, support personnel turnover rates, packaging, handling and transportation rates, etc., also are used in the ARPV LCC model. These standard rates are combined with best available estimates of field MTBFs, average repair times per maintenance action, hardware/software support equipment costs, etc., as required model inputs.

The output of this model is the estimate of LCC for a given processing system. Iterations and sensitivity analyses are then performed to determine the accuracy or limitations of this estimate. The selected LCC model yields an accumulated dollar value for the operational period.

2. Operational Considerations

The life-cycle scenario and operational concept data for the ARPV which was hypothesized for this study is summarized as follows:

Nine squadrons of 50 aircraft each (with strength of 450 aircraft at end of 10-year period)

5,000 flying hours in a 10-year, peacetime, training period (5,000 one-hour flights)

Two percent attrition in peacetime training (100 aircraft)

Original acquisition of 550 aircraft with 450 left for the 30-day combat at the end of 10 years

5,000 flying hours of combat operation in the 30-day conflict (with most of the conflict in the first 10 days)

Peacetime deployment is three squadrons at three bases. (Wartime deployment is nine squadrons in three clusters of three squadron bases)

ARPVs will operate from austere, dispersed bases which are located 10- to 30-miles from manned aircraft bases which will provide the peacetime logistical support.

Details of the ARPV mission scenarios are covered in Appendix A of this report.

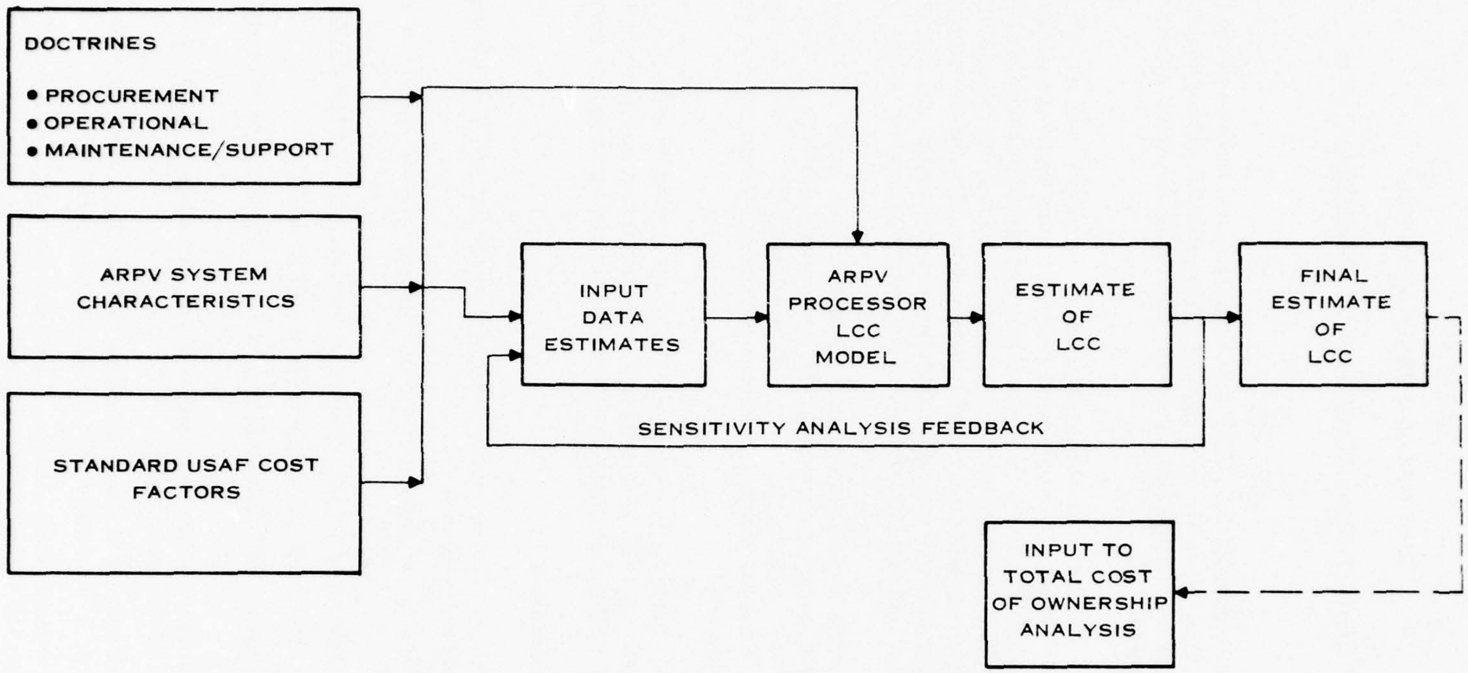

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Figure 24. ARPV Processing System LCC Analysis

The basic parameters for the processing system LCC analysis which are derived from the life-cycle scenario are:

550 ARPV vehicles (procured at the rates of 55/year for 10 years or 275/year for 2 years)

1.5 operating hours per year per ARPV (based on 1 flying hour per year per aircraft and on a 1.5:1 operating to flying hour rate

10-year peacetime period followed by a 30-day conflict in the 11th year.

These and other operational factors were used in the LCC analysis which is discussed in subsection IV.B.

3. Maintenance Considerations

Maintenance considerations were driven by the following factors:

Desire to maintain operational readiness during the entire peacetime period

Detailed reliability predictions of the various processor architectures

Prevailing USAF maintenance doctrines and policies.

These factors combine to yield a three-level maintenance philosophy (organizational or flight line, intermediate, and depot levels) using the USAF doctrine of no preventive maintenance. Additional details on reliability and maintainability analyses for the ARPV processing systems may be found in Section III of this report.

B. ANALYSIS OF LIFE-CYCLE COST

1. Background

In order to select the most appropriate LCC model for this study, a number of currently available LCC models were reviewed. In the selection process, LCC models from all the military services were considered including a number of versions of the basic AFLC model, the GPS model, and the ARPV-AFLC model. In addition, a model developed by Texas Instruments was considered. This model incorporates a large number of desirable features from other currently available models. Experience with the Texas Instruments model has proven it to be especially useful in the early analysis phases of a program.

After an evaluation of these various models, the Texas Instruments LCC model was selected as the most appropriate one for use in this study. This model contains appropriate cost categories; it is tailored for analysis in developmental applications, and it is computerized. It is flexible and may be easily expanded or modified for application in the early study phases of programs where the amount of definition is not completely known or easily estimated. For example, the number of line-item introductions is based on a total line-item count without regard to coding, as opposed to defining P-coded line items as found in other models. A detailed discussion of this model is presented in Appendix F.

2. Methodology

With the LCC model selected, only a few alterations of the individual equations were required for adaptation to the ARPV problem. The data which had to be estimated was categorized and assigned to individuals who were either specialists or who were very familiar with those areas to be estimated. All estimates were made in terms of constant 1976 dollars. Also mature technology was assumed for all three processor system designs. Some data, such as standard cost factors, were available from AFLC and other sources. Appendix G is a collection of the final input data used in the LCC analysis. The use of cost estimating relationships (CERs) was unfortunately held to a minimum because of a lack of open literature and CERs in the areas of microprocessors, computers, etc.

After collection and review of this estimated data, the data was input to the ARPV LCC model. Separate LCC estimates were determined for the three processing systems (Centralized, Hybrid and DP/M) with appropriate averaging over the three ARPV missions (strike, recce, and EW).

3. Results

The results of the life-cycle cost analysis are summarized in Table 30 for the two procurement "options", i.e., 55 systems/year for 10 years and 275 systems/year for 2 years. As expected, the shorter procurement time case is more advantageous than the smaller-quantity longer-procurement-time case. The lowest LCC from this classical LCC analysis is the value of $71,307,003 for the Hybrid system, 275 systems/year buy.

It is interesting to note in this analysis that the acquisition cost for each system is greater than the sustaining cost. For the 275 systems/year buy, the acquisition to sustaining cost ratio for the Hybrid system is 1.51:1; the corresponding ratios for the other two systems are 2.00:1 (DP/M) and 2.24:1 (Centralized). These ratios are lower than normally expected for avionics systems because of the relatively low operating hours (1.5 hours of operating time per year) and the high reliabilities predicted for each of the three processor configurations.

The LCC results in Table 30 do not reflect the 30-day conflict period. For simplicity of analysis, this period was chosen to follow the 10 years of peacetime. The results of this additional conflict period do not alter the conclusions reached; i.e., that the Hybrid system exhibits the lowest life-cycle cost.

4. Other Considerations

The acquisition-to-sustaining-cost ratio is determined in part by the need for operational readiness, since sustaining factors such as logistics, training, manuals, and maintenance were held at a level compatible with entering the 30-day conflict at any time during the 10-year period. With the small amount of operating hours per year per aircraft, the ARPV sustaining effort more clearly approximates a missile or guided weapons sustaining effort in which activities are limited to system test and verification on a sampling basis and repair of the faulty systems. In the latter situation, Texas Instruments has observed that LCC analyses generally indicate an approximate 4:1 acquisition to sustaining cost ratio. If the missile/guided-weapons sustaining philosophy were adopted for the ARPV, the acquisition cost of $42,919,100 for the Hybrid system (Table 30) would indicate a sustaining cost of $10,729,775. This would yield a total cost for the 10-year peacetime period of $53,648,875 or a reduction of 24.8 percent in the life-cycle cost.

TABLE 30. SUMMARY OF ARPV PROCESSING SYSTEM LCC RESULTS

	Processing System		
	Centralized (C)	Hybrid (H)	DP/M
55 Systems/Year, 10 Years			
Acquisition Cost	$120,172,400	$69,742,600	$104,150,400
Sustaining Cost	31,392,770	27,513,237	29,644,200
Life Cycle Cost (Constant 1976 Dollars)	$151,565,170	$97,255,837	$133,794,600
275 Systems/Year, 2 Years			
Acquisition Cost	$ 72,626,640	$ 42,919,100	$ 61,041,560
Sustaining Cost	32,463,753	28,387,903	30,500,587
Life Cycle Cost (Constant 1976 Dollars)	$105,090,393	$ 71,307,003	$ 91,542,147

5. Sensitivities Analysis

The dominant factor or driver in the life-cycle cost for all systems considered is the per-unit acquisition cost. For this reason, extensive sensitivity analyses were not run on sustaining cost factors. A sensitivity analysis was conducted for the procurement quantities, i.e., 55 systems/year purchased for 10-years or 275 systems/year purchased for 2-years. The other two principal life-cycle cost factors, reliability and operating hours, also were investigated.

Results of the procurement quantity sensitivities were summarized in Table 30. As expected, the larger quantity-shorter procurement time yielded the lowest LCC.

For the second sensitivity analysis, the effect of system reliability was examined. A variation of less than 0.1 percent resulted in the total life-cycle cost for a variation of an order of magnitude decrease in the mean-time-between-failure (MTBF or XTBF) and the mean-time-between maintenance action (MTBMA or XTBM). These results are somewhat distorted in that the processing system unit price was not altered in this analysis. In reality, a system with an order of magnitude lower MTBF would not be as expensive as the more reliable system.

The final sensitivity analysis involved the operating hours of the processing system. For a variation of 50 to 450 operating hours per year, an increase in the life-cycle cost of less than 2 percent resulted.

Both the MTBF and operating-hours sensitivities indicated that the reliability of the Hybrid system was indeed cost-effective from an LCC point of view.

In order to show the impact of the cost categories, the LCC for each system (for the 275/year buy) was examined for the driver categories. A summary of the major cost categories is presented in Table 31 through Table 33. As stated before, the unit cost is the principal cost factor for both the acquisition cost and life-cycle cost. The sustaining costs contribute approximately 31 percent to the total LCC value for each system. Recurring data management is the dominant sustaining cost category.

TABLE 31. ANALYSIS OF CENTRALIZED SYSTEM LCC DRIVERS

	Value	Percent of Acquisition Cost	Percent of LCC
Acquisition Costs			
Design and development	$ 2,041,233	2.81	1.94
Initial technical data	2,055,900	2.83	1.96
Other nonrecurring cost	133,430	0.18	0.13
Prime equipment/initial spares (includes installation and first destination cost)	67,983,153	93.61	64.69
Support equipment/initial spares	412,924	0.57	0.39
	$72,626,640	100.00	69.11
Sustaining Costs			
Maintenance labor	$ 998	0.00	0.00
Maintenance material	4,668	0.01	0.00
Maintenance documentation	126	0.00	0.00
Maintenance packaging and transportation	41	0.00	0.00
Condemnation	4,755,438	14.65	4.53
Checkout	1,297,694	4.00	1.24
Energy consumption	0	0.00	0.00
Supply management	812,186	2.50	0.77
Facility space	7,024	0.02	0.01
Recurring training	322,680	1.00	0.31
Recurring data management	22,922,697	70.61	21.81
Support equipment maintenance	265,890	0.82	0.25
Software maintenance	2,074,311	6.39	1.97
	$32,463,753	100.00	30.89
Life Cycle Cost	$105,090,393		100.00

Early analyses of these three processor systems were made using a 5 percent condemnation rate. This value was judged to yield distorted sustaining and life-cycle costs. The condemnation rate was reduced to 1 percent for the analysis shown in this report. The condemnation cost category contributes approximately 4 percent to the life-cycle cost value for each of the three systems considered.

The possible effect of using bit slice or nonhomogeneous processing elements was not analyzed in detail. However, qualitatively, it can be stated that the effect of such changes would be to increase the initial and recurring training, initial and recurring data, and initial and recurring logistical costs in proportion to the selected mix.

TABLE 32. ANALYSIS OF HYBRID SYSTEM LCC DRIVERS

	Value	Percent of Acquisition Cost	Percent of LCC
Acquisition Costs			
Design and development	$ 2,384,756	5.56	3.34
Initial and technical data	1,842,750	4.29	2.58
Other nonrecurring cost	128,929	0.30	0.18
Prime equipment/initial spares (includes installation and first destination costs)	38,364,970	89.39	53.80
Support equipment/initial spares	197,695	0.46	0.28
	$42,919,100	100.00	60.18
Sustaining Costs			
Maintenance labor	892	0.00	0.00
Maintenance material	4,699	0.02	0.01
Maintenance documentation	145	0.00	0.00
Maintenance packaging and transportation	17	0.00	0.00
Condemnation	2,757,428	9.71	3.87
Checkout	1,334,975	4.70	1.87
Energy consumption	0	0.00	0.00
Supply management	631,282	2.22	0.89
Facility space	7,226	0.03	0.01
Recurring training	331,950	1.17	0.47
Recurring data management	21,136,406	74.46	29.64
Support equipment maintenance	151,028	0.53	0.21
Software maintenance	2,031,855	7.16	2.85
	$28,387,903	100.00	39.82
Life Cycle Cost	$71,307,003		100.00

C. TOTAL COST OF OWNERSHIP

Conventional LCC is just one element in determining total cost of ownership for an ARPV processing system. Other factors such as catastrophic loss of ARPVs through processing system reliability failure should be considered. The appropriate ARPV attrition rate can be determined from the following expression:

$$\text{Attrition Rate} = 1 - e^{-t/MTBF}$$

where t is the total flight duration.

For a 1-hour flight time, the attrition rate and number of ARPVs lost in a 10-year period are shown in Table 34. This analysis shows that the Hybrid system provides minimum total of cost-of-ownership including both conventional LCC and costs associated with processing-system-related ARPV attrition.

TABLE 33. ANALYSIS OF DP/M SYSTEM LCC DRIVERS

	Value	Percent of Acquisition Cost	Percent of LCC
Acquisition Costs			
Design and development	$ 2,384,756	3.91	2.61
Initial technical data	1,842,750	3.02	2.01
Other nonrecurring cost	128,909	0.21	0.14
Prime equipment/initial spares (includes installation and first destination costs)	56,487,450	92.54	61.71
Support equipment/initial spares	197,695	0.32	0.22
	$61,041,560	100.00	66.69
Sustaining Costs			
Maintenance labor	980	0.00	0.00
Maintenance material	7,077	0.02	0.01
Maintenance documentation	219	0.00	0.00
Maintenance packaging and transportation	25	0.00	0.00
Condemnation	4,170,517	13.67	4.56
Checkout	1,371,290	4.50	1.50
Energy consumption	0	0.00	0.00
Supply management	648,454	2.13	0.71
Facility space	7,423	0.02	0.01
Recurring training	340,980	1.12	0.37
Recurring data management	21,711,360	71.18	23.70
Support equipment maintenance	155,136	0.51	0.17
Software maintenance	2,087,126	6.85	2.28
	$30,500,587	100.00	33.31
Life Cycle Cost	$91,542,147		100.00

TABLE 34. ARPV ATTRITION RATE DUE TO PROCESSING SYSTEM FAILURE

Processing System	Flight Critical MTBF at 45°C (hours)	ARPV Attrition Rates for 1-Hour Flight	Number of ARPVs Lost in 5,000 1-Hour Sorties
Centralized	1,485	0.000673	3.36
DP/M	1,586	0.000630	3.15
Hybrid	1,874	0.000533	2.66

SECTION V

CONCLUSIONS AND RECOMMENDATIONS

Of the three processing systems described in Section III of this report, the Hybrid system is recommended as the most promising approach for the ARPV avionics application. Selection of this distributed processing network as the recommended design is based primarily on its low LCC compared to the other systems considered in this study. In addition to the minimum LCC, the Hybrid system also provides the best system performance in terms of flight-critical reliability. Superior flight-critical reliability of the Hybrid system results from functional partitioning of the processing tasks and from the natural hardware redundancy which occurs in the distributed network approach.

Results from this study are particularly significant in view of the current widespread Air Force interest in reducing system LCC through standardization of hardware and software. An important factor contributing to the low LCC for the Hybrid system is the extensive use of standard modules throughout the distributed processing network. Results from this study, in particular the modular design of the basic PE, should be widely applicable to other Air Force avionic processing problems, including manned aircraft systems.

In order to design specific candidate processing systems, it was necessary to postulate representative ARPV mission scenarios and associated processing requirements. It is reasonable to ask how sensitive the results of this study are to the assumed scenarios and processing requirements. Since the actual ARPV requirements are still in an early stage of definition, there is considerable uncertainty as to how close the representative processing requirements shown in Appendix C of this report will be to the actual requirements ultimately defined for the ARPV. Reasonable uncertainty in either individual algorithm estimates or the total processing estimate does not affect the selection of the Hybrid system as the recommended ARPV processing system design. The relatively light loading of the Hybrid system throughput (25 percent) and memory (65 percent) provides a comfortable margin for accommodating possible increases in processing requirements. In the unlikely event that actual ARPV requirements exceed the capacity of the Hybrid system as currently configured, throughput and/or memory can easily be expanded in small cost-effective modular increments.

As part of this program, bus traffic was analyzed for each of the three candidate processing systems. In the case of the Hybrid system, peak traffic on the network bus was determined to be approximately 94 kilobits per second, which represents 9.4 percent of the MIL-STD-1553A bus capacity. Again, there is ample margin for growth if the actual ARPV processing requirements generate more bus traffic than the representative requirements used in this study. If bus traffic problems are eventually encountered, the Hybrid system can be modified slightly by introduction of "local" buses between specific PEs or groups of PEs to relieve congestion on the primary or "global" bus. Both the global and local buses would operate according to the requirements of MIL-STD-1553A. At this time there does not appear to be a need for high-data-rate bus concepts (e.g., fiber-optic data bus) in the ARPV application.

For the life cycle scenario defined in Section IV of this report, acquisition cost for the Hybrid system (as well as the other systems) was found to be the dominant factor in total LCC. The system design and, therefore, the acquisition cost for the Hybrid system are based on currently available components and devices. It is possible in the 1980 time frame that acquisition cost can be reduced through use of new components or devices.

Three specific developments are expected by the early 1980s which could improve the implementation of the Hybrid system:

262,144-bit nonvolatile RAM memory on a single chip

A microprocessor equivalent to the SBP 9900 with user accessible memory on the chip

A single LSI chip containing the digital logic portion of the MIL-STD-1553A interface.

Using the current design as described in this report, a fully expanded PE for the Hybrid network requires nine 4.5- by 5.6-inch printed wiring boards. The above developments could be used to produce a PE of equivalent performance (throughput, memory, and I/O capability) with only three boards. Such a large reduction in the number of boards or modules required for a full performance PE could have a dramatic effect on all Hybrid system parameters, including size, weight, power, and cost. Also, the use of nonvolatile RAM memory could eliminate the need for a backup battery power source in the Hybrid system design.

Future Air Force work on the ARPV processing problem should include the development of key components (e.g., the MIL-STD-1553A interface chip) which can reduce the cost of the basic Hybrid system. There is also a need for a distributed network development facility within the Air Force which can be used for actual test and evaluation of specific distributed processing configurations. Such a facility could be based on currently available minicomputers (TI 990 family) which are software compatible with the SBP 9900 microprocessor. Such a facility would provide a relatively low cost way to accurately measure bus loading, algorithm performance and other detailed system parameters of interest in the ARPV application. The minicomputer-based development facility would be general purpose in nature and could also be used to assist in development phases of other Air Force processing applications.

APPENDIX A

REPRESENTATIVE ARPV MISSION SCENARIOS AND FUNCTIONS

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APPENDIX A

REPRESENTATIVE ARPV MISSION SCENARIOS AND FUNCTIONS

I. ARPV MISSION SCENARIOS

In arriving at specific mission scenarios, it is necessary to both define and limit the operational environment and the tasks to be accomplished by the remotely piloted vehicles. The following key assumptions were used in developing the three scenarios; one each for a strike mission, a reconnaissance mission, and an electronic warfare mission:

1. The missions will be performed in an Eastern European combat environment involving NATO and the Warsaw Pact nations.
2. The ARPVs will perform their mission in the presence of the dense antiaircraft defenses described in the Air Force Study on Defense Suppression (HAVE LIME).
3. Reconnaissance and strike missions may be conducted in waves but each sortie will be flown independently (i.e., no formation or stationkeeping other than basic navigation).
4. Active electronic warfare and chaff-dispensing missions will require several ARPVs to operate simultaneously in some type of loose formation.
5. Strike and reconnaissance ARPVs will depend upon high speed and low altitude for survival while conducting single aircraft missions beyond the FEBA.
6. Due to limited payloads, strike ARPVs will not have self-protect EW features such as chaff and/or flare dispensers or active jammers.
7. ARPVs which must penetrate enemy defenses at higher altitudes may have self-protect EW features to aid in penetration if they do not degrade basic EW support capability.
8. Reconnaissance ARPVs which penetrate enemy defenses at low altitude, may have self-protect EW features if they significantly improve survivability.
9. All sorties will be preplanned in detail with no deviations from the planned mission except for equipment failure or recall, where this is feasible.
10. An adequate intelligence data base on enemy deployment will be available for planning all strike and reconnaissance missions and it will be kept current using real or near real-time ARPV and manned aircraft reconnaissance.
11. Preplanned strike missions will be primarily against heavily defended targets at known locations and preferably with acquisition and recognition features which are not dependent upon electro-optical sensor resolution lines on the target.
12. Most strike missions will be for defense suppression by knocking air defense radars off the air but the strike ARPVs will also be able to attack a limited set of nondefense targets, such as airfields and armored columns using area denial weapons such as mines and other target activated munitions.

While most of the segments for the three different types of missions will involve different functions, there are several mission segments which will be common to all missions. These are the segments involving preflight and postflight activities and launch and recovery. These segments are only slightly mission dependent. The first segment is for ARPV vehicle and equipment checkout which will include loading from storage, the basic operating programs for all processors requiring this. To the maximum extent feasible, this checkout should be accomplished using built-in test to avoid requirements to connect the ARPVs to external test equipment. The next segment consists of loading expendables and software for the specific sortie to be accomplished by the ARPV. This software will control all subsequent segments of the ARPV mission and will include such items as the timing, ground track, airspeed and altitude to be flown on each segment, navigation update checkpoints (including checkpoint signatures), equipment operating instructions, operating frequencies, JTIDS data, IFF codes to be used, when to arm weapons and release mechanisms, when and where to operate sensors and EW equipment, contingency instructions if applicable, other software data or instructions necessary to complete the mission and return to the recovery control area and recovery instructions. The expendables loaded in this segment are mission peculiar and include weapons, sensor film and/or recording tape, and EW expendables. Fuel and other similar aircraft expendables will be loaded during checkout, if not already loaded. Where rocket boosters are required for launch, they will be attached during the expendable and software loading segment.

The next common segment for all three types of missions is launch and initial climbout, including any ground movement to get into launch position. This movement and engine start will probably be a manual operation rather than one controlled by software.

After engine start, proper operation of the engine and electrical, hydraulic and other engine subsystems will be automatically verified by built-in test and software, after which the ARPV is ready for launch. Launch may be by catapult, rocket boost, or other means depending upon ARPV design. In any event, it will be under automatic control aboard the ARPV. It will be initiated on command from the local ARPV Launch and Recovery Control Unit (LRCU), which will monitor the launch and climbout and issue corrective commands to the onboard automatic control system as necessary. Depending upon the ARPV design and performance, manual override of the automatic flight-control system may be provided. However, manual control will be of doubtful value, and even mission aborts with immediate recovery will probably have to be handled automatically with suitable software. The actual abort and changeover to automatic recovery would not occur until commanded by the ARPV operator. After launch, an automatically controlled climb profile and ground path would be followed. This would be monitored by the LRCU which would hand off control to an RPV Control and Operations Unit (COU) at a preselected location and time. This RPV Control and Operations Unit would have operational control of the RPV throughout the remainder of its mission and would operate under and possibly as a part of the tactical Combat Operations Center (COC).

The remainder of the mission under the COU has essentially mission peculiar segments which will be described separately for each of the three missions. The COU will control the ARPV until it approaches its home base and begins its descent. At a preselected location, the COU will transfer control to the LRCU for descent and recovery. To permit properly spacing the returning ARPVs, the ARPV must be programmed to execute time adjustment maneuvers upon command. These maneuvers will include turns to extend the approach to recovery as well as orbits and possibly holding patterns. As with launch and climbout, descent and recovery will be fully automatic with the recovery operator being able to command changes in the automatic system. Recovery will include automatic engine shutdown after hook engagement, barrier engagement, or touchdown as appropriate for the recovery method.

Following the recovery segment, there are two more mission segments which are common to all three missions. These are similar to the first two prelaunch segments and are actually combined with them if the ARPV is to be immediately turned around for another sortie. The first postflight segment includes downloading film and/or recording tape, check of all subsystems using BIT and AGE test sets where required, and a physical exterior inspection for battle damage. Those RPVs which are found ready to go again are refueled and are ready for the second prelaunch segment, loading of expendables and software for the next mission. Those which are not ready to go again are scheduled for immediate maintenance if the deficiency can be quickly corrected or for delayed maintenance if it is more difficult to correct.

A. ARPV STRIKE MISSION SCENARIO

The ARPV strike mission has the most complicated scenario, with more segments involving different functions than the other two missions, especially if target acquisition and weapon delivery sensors are used. While many strike missions can and will be conducted by releasing area weapons at a measured position against a target at a known location, ARPV position errors and other factors may require target acquisition with onboard sensors for strike. Since this latter mission will include all segments of the strike based on position only, plus a sensor target acquisition segment, the strike using sensor target acquisition will be used for scenario development. The segments will be numbered for cross referencing the discussion with Figure A-1 which shows the mission profile and Figure A-2 which summarizes the segments and their sequence.

The first three segments (numbered 1, 2 and 3) are checkout, loading and launch segments which have already been discussed. After launch, the ARPV will follow a preprogrammed climb schedule and ground track, which can be altered upon command from the LRCU. Alteration of the preprogrammed schedule should only be necessary under unusual circumstances.

At a preselected altitude and/or position, control will be transferred from the RPV LRCU to the RPV COU in accordance with the premission plan (segment 4). The COU will maintain control and monitoring responsibility, throughout the mission until the RPV reaches its initial approach altitude upon return from the mission. At that time, RPV control will be returned to the LRCU for final approach and recovery of the ARPV (segments 13 and 14).

The ARPV will climb to the cruise altitude selected in preflight planning and maintain this altitude until approaching the FEBA. This segment may involve several preplanned changes in ground track and altitude. During this segment, which is over friendly territory, accurate navigation update using radio navigation signals (e.g., GPS, JTIDS or line-of-sight DME) will be used. As the FEBA is approached, the ARPV will make an automatic descent to penetration altitude, based on its navigation position (segment 6). As penetration altitude of 200 to 400 feet is approached, terrain following will be initiated using the radar altimeter and, if necessary, terrain-following radar. Radio navigation update will be used to ensure the ARPV navigation system can acquire a checkpoint for navigation update prior to passing the FEBA. This will permit a smooth transition in the event enemy jammers disrupt radio navigation signals beyond the FEBA, either enroute to or in the target area.

Penetration to the target area (segment 7) will be at very low altitude along a preplanned ground track. It will involve several legs of varying length with different ground tracks. These will be based on such factors as avoiding known defense positions, minimizing terrain following problems and preventing the enemy from determining the target for each sortie. A medium performance INS will be required for handling some of the reconnaissance and weapon delivery

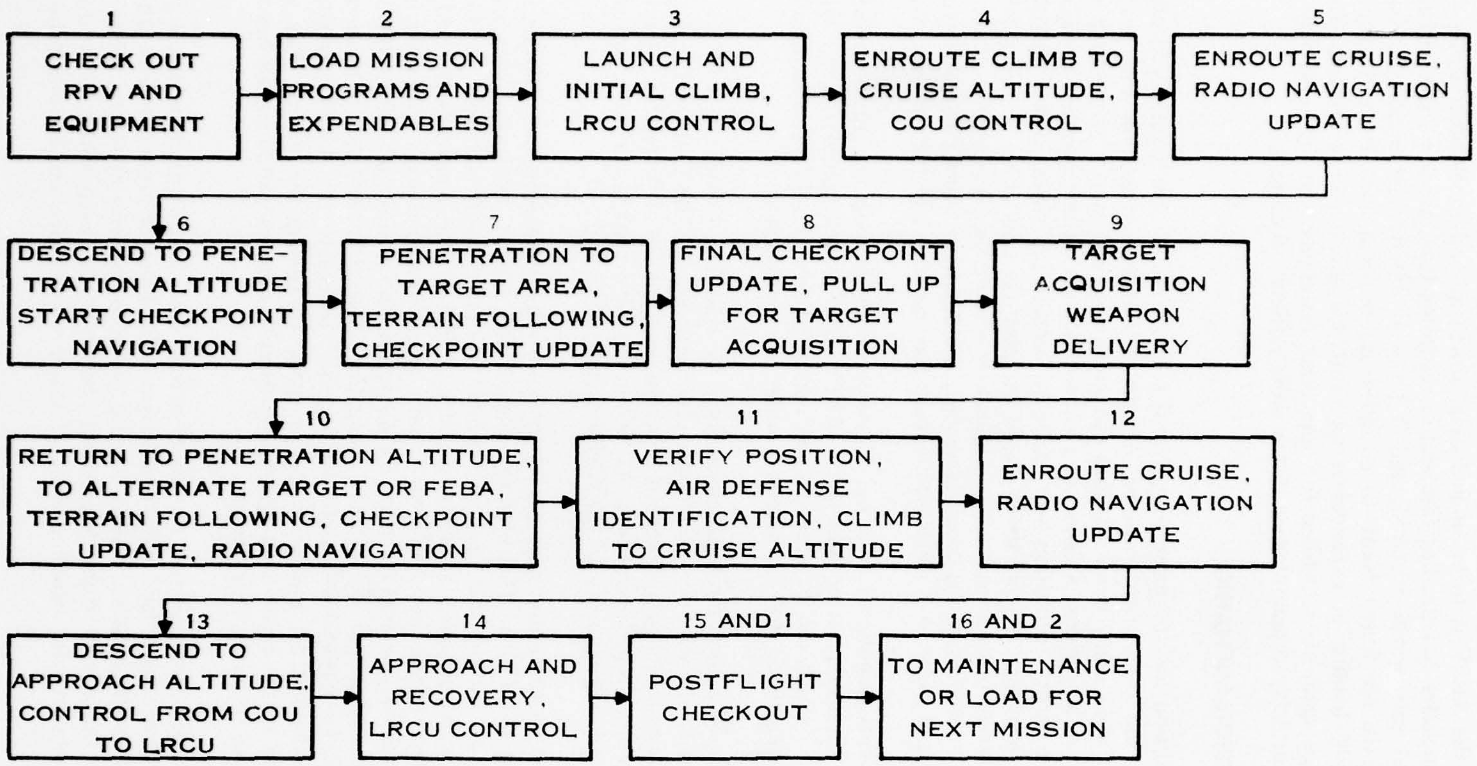

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Figure A-1. Strike Mission Segment Sequence and Summary

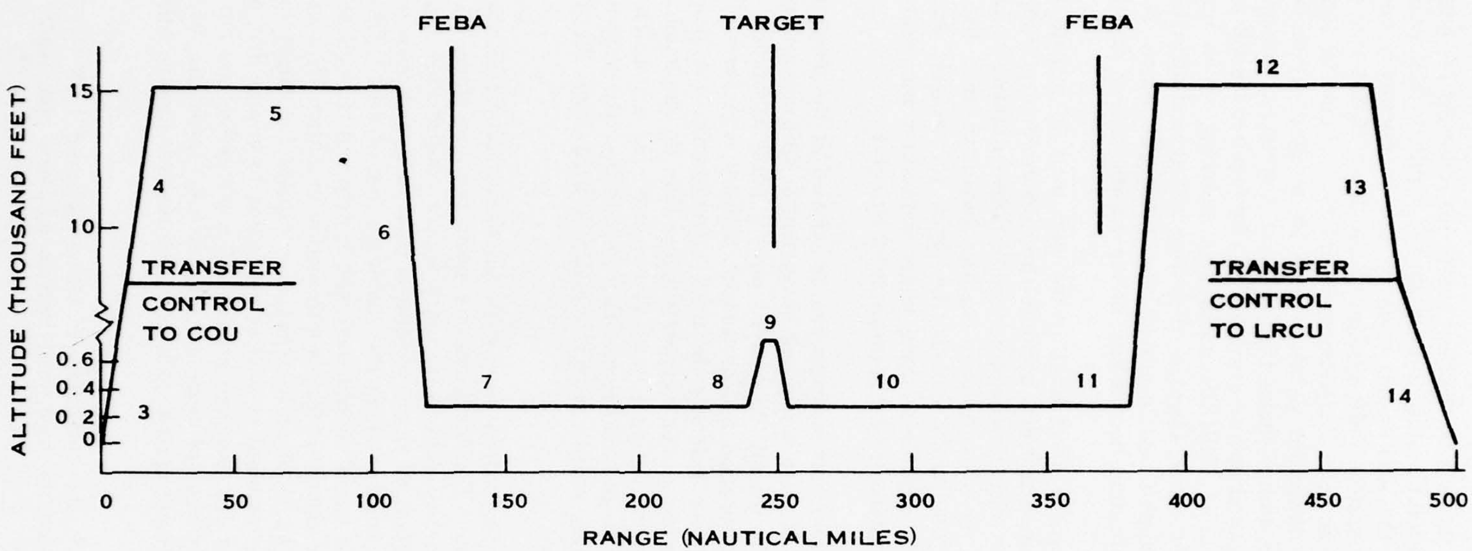

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Figure A-2. Strike Mission Profile and Numbered Mission Segments problems of the ARPV and this will be the basic sensor for following the ground track. However, it will require frequent position updating to maintain the required track accuracy. As long as RF signals can be received by the ARPV, this updating can be essentially continuous from such sources as GPS, JTIDS or special DME systems. Since these signals can be jammed and the Warsaw Pact countries have an extensive jamming capability, it should be assumed that there will be large areas where RF navigation signals cannot be received. These areas will include a minimum radius of 10 miles around major tactical target complexes. To handle this situation, an onboard self-contained navigation update capability will be required. It will probably be a ground checkpoint update system using TERCOM, radar map matching, or an optical area correlator using a suitable day or night sensor. Checkpoint spacing will depend upon INS drift rate and the area coverage of the checkpoint update system, but there will usually be one at least every 10 miles. Checkpoint identification data is part of the specific mission data loaded in segment 2.

The final inbound enroute checkpoint is the one used to initiate target acquisition in mission segment 8. For weapon delivery, accurate three-dimensional position is required. Therefore, this checkpoint will be selected to permit vertical position update using the radar altimeter. This checkpoint needs to be close enough to the target so that INS drift, plus update inaccuracies, will not put the ARPV outside the limits for weapon delivery based on INS position alone or for target acquisition using target acquisition and weapon delivery sensors. Obviously, the blind delivery requirement is much more stringent.

Since none of the current area weapons can be released at the penetration altitude, pullup to at least minimum release altitude is required in segment 8. This pullup can begin over the final checkpoint. However, it will usually be delayed until a point at or near the minimum range which will permit target acquisition and/or weapon delivery maneuvers. This will be done to reduce exposure to enemy air defenses. In most circumstances the pullup altitude for the optimum release conditions for an area weapon is higher than the minimum release altitude. This factor, plus weather and enemy defenses must all be considered in mission planning and it will probably be necessary to plan and load several target acquisition and weapon delivery profiles. If so, one would be the primary profile to be automatically used unless the ARPV operator issued a command to do otherwise.

Segment 9 is short but is critical because its successful accomplishment is the only reason for the strike ARPV mission. For blind delivery using position alone, no target acquisition is required. However, for increased delivery accuracy and/or confirmation that the assigned target was attacked, target acquisition by an electro-optical (EO) or other sensor will often be required. For this, automatic sensor pointing along the computed line of sight (LOS) to the target (based on ARPV INS position and target coordinates) will be required, as well as transmission of any required data to the ARPV operator, for his information or action. With an EO sensor, operator action will almost always be required to select or designate the target or aimpoint. For this, two-way data links will be required as well as processing to ensure that ARPV commands are received and understood or for alternate action in the event they are not. Another processing problem for this segment is whether weapon release is fully automatic, without operator input, and if automatic, how to ensure against inadvertent release over friendly territory in the event of a malfunction.

Throughout segment 9, the computed or sensor-measured LOS will be used for weapon delivery computations, which, in turn, will provide guidance commands to the ARPV flight control subsystem. In addition, where sensors are used, the weapon delivery computer must be able to decide when or if it should change from computed to measured LOS.

Segment 10 starts when the ARPV passes the weapon release point. At this point the ARPV descends to the penetration altitude and begins terrain following and follows one of two automatically selected preprogrammed options. If the weapon was not released for any reason other than malfunction of the release mechanism after receiving a valid release signal, the ARPV will proceed to an alternate target and repeat segments 8 and 9. This alternate can be the original target after following a navigation sequence to bring it into position for a second attack. If the weapon has been released, either on a primary or alternate target, the program to return to the FEBA is selected. This requires following the programmed ground track using checkpoints (and RF navigation when it becomes available).

On crossing the FEBA (a navigation position as far as the ARPV is concerned) mission segment 11 begins. The ARPV updates its navigation system and at the designated position provides any required air defense identification (including both maneuvers and IFF responses) and begins a climb to its assigned cruise altitude. After crossing the FEBA, RF navigation will be used in segment 12. Enemy jamming will no longer be effective and checkpoint navigation is much less accurate at higher altitude. A preprogrammed ground track and flight profile will be followed unless the ARPV operator at the COU issues program change commands.

At a preselected range from the ARPV base, it will begin a programmed descent to approach altitude (segment 13) and control will be exchanged between the COU and the LRCU. Approach and recovery (segment 14) will be automatic, subject to LRCU change commands. This and segments 15 and 16 were discussed previously as common segments to all three types of ARPV missions. As shown in Figure A-2, segments 15 and 16 become segments 1 and 2 for the next mission for those ARPVs which checkout as ready in the postflight check.

Figure A-2 shows the approximate strike mission profile with each of the noncommon segments numbered. Altitudes and ranges are representative of a typical mission and will be subject to adjustment depending upon the combat situation, other air traffic, and the ARPV performance versus altitude and range.

B. ARPV RECONNAISSANCE MISSION SCENARIO

The ARPV reconnaissance mission is similar to the strike mission except that it will usually have several point targets (or possibly a long strip target) and may use more than one type of sensor on a mission. Also, with sensors which have wide-angle lateral coverage, it may not be necessary for the ARPV to pull up to a higher altitude at the target and, if this is required, the altitude will still be lower than that for strike target acquisition or weapon delivery.

Figure A-3 provides a reconnaissance mission segment sequence and summary while Figure A-4 shows a mission profile. For both figures, the segments are numbered to correlate the mission discussion with the figures. The first six segments are the same as those for a strike mission and will not be repeated here. Also, for purposes of this study more than one sensor is assumed for the reconnaissance ARPV. This was done to increase the functions to be performed on the mission, although only a single sensor will be used on most combat missions.

Like the strike missions the reconnaissance missions will often involve several aircraft but each sortie will operate independently of the others. The reconnaissance and strike sorties will

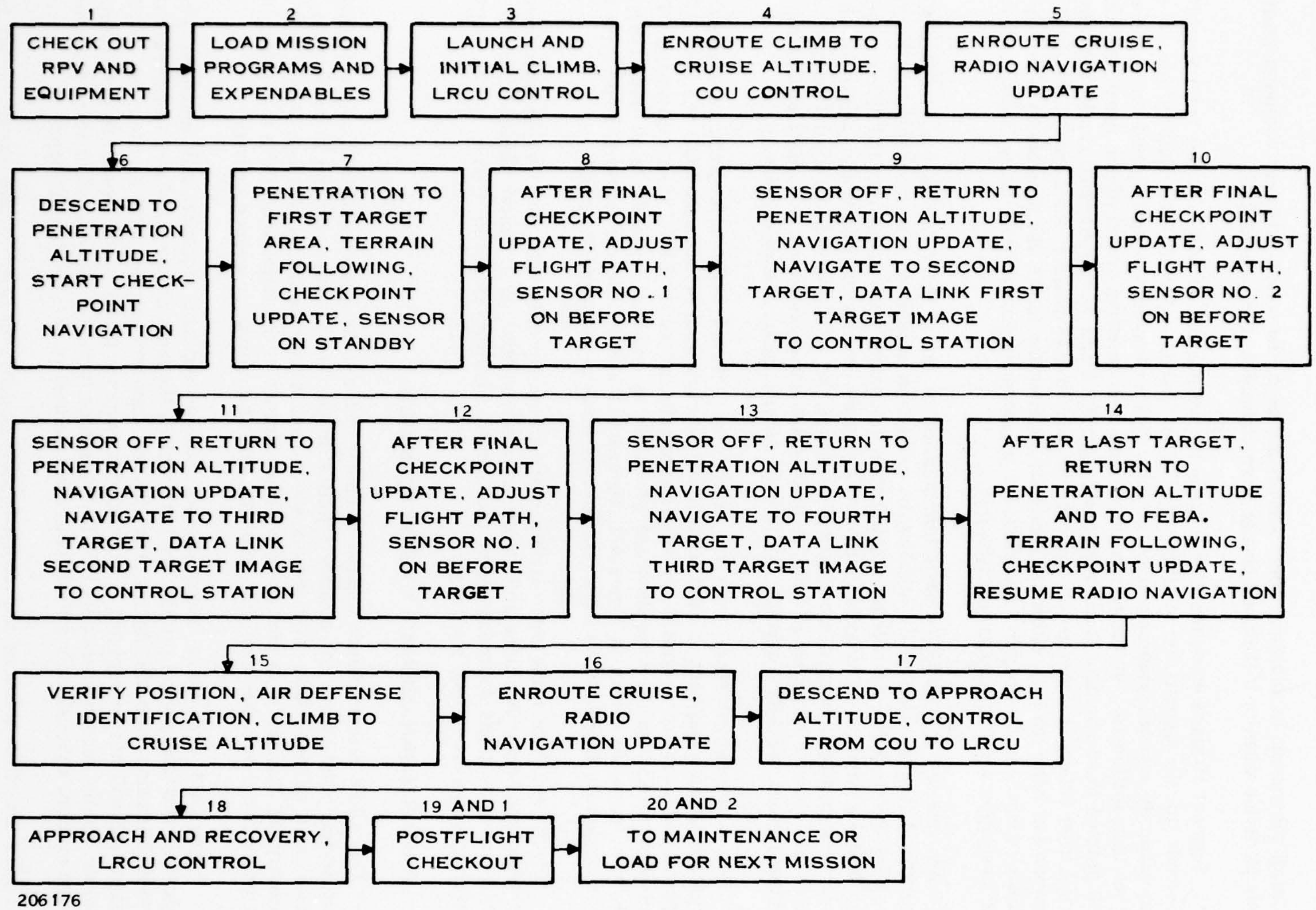

Figure A-3. Reconnaissance Mission Segment Sequence and Summary

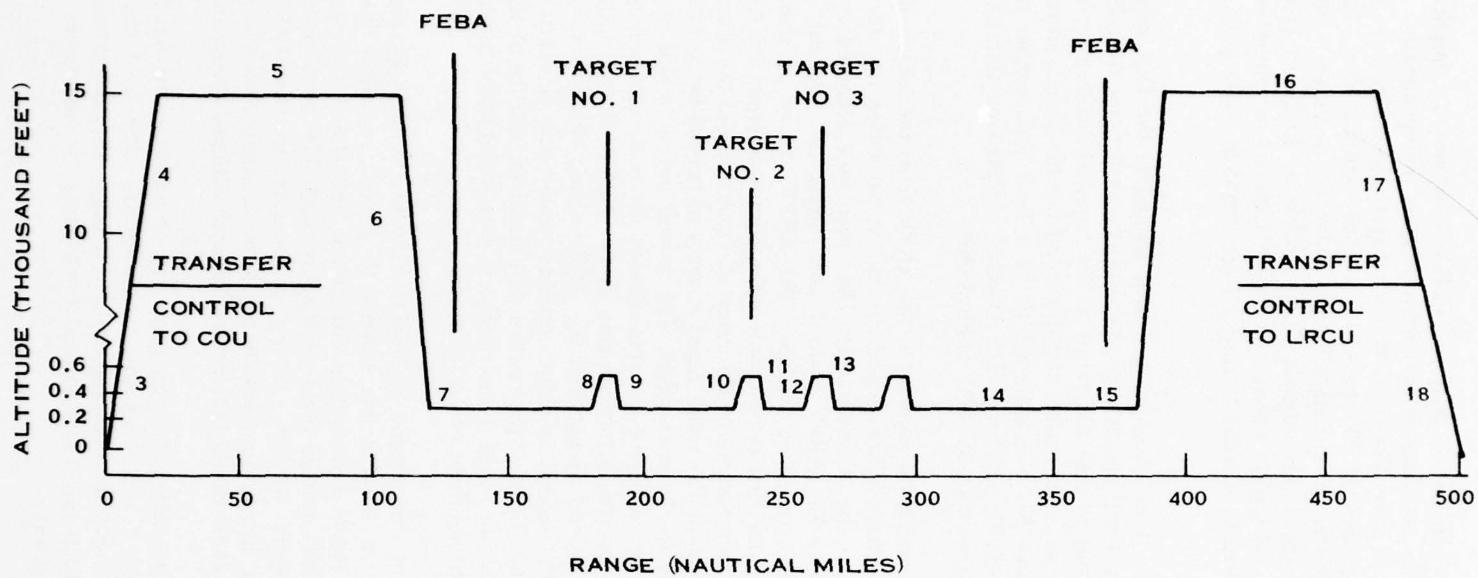

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Figure A-4. Reconnaissance Mission Profile and Numbered Mission Segments probably be scheduled for penetration past the FEBA in waves to complicate the enemy air defense problems. Since the reconnaissance sorties operate independently, they will have to depend upon high speed at very low altitude for survival against enemy air defenses. Thus, segment number 7 will be flown at 200 to 400 feet above ground level. This will be accomplished using a radar altimeter, a terrain-following radar (if necessary) and a ground track selected to minimize high speed, low-altitude flying problems. Frequent ground-track heading changes will be used with navigation update checkpoints spaced to minimize acquisition problems. Sensors will be switched to standby in time for any required warmup or stabilization, prior to reaching the first target.

In mission segment 8, a final checkpoint is used to update the INS, when close enough to the target to ensure the target will pass within adequate lateral distance for good sensor coverage. The ground track is corrected to pass the target at the required distance for the desired vertical or oblique target imagery and, at a preselected distance from the target, altitude is adjusted and the sensor turned on. Sensor No. 1 is assumed to be a laser line scanner designed to obtain reflectance imagery in the visible spectrum. The imagery is stored on film and on video tape if imagery is to be data linked back to the RPV control unit.

After passing the first target, for segment 9, the ARPV turns the sensor off, and descends to penetration altitude. Using terrain-following and checkpoint navigation update, the ARPV follows the preprogrammed route to the second target. The video tape recorded imagery of the first target may be data linked to the ARPV control unit during this segment. If this is required, several preprogrammed options must be available. The ARPV will be programmed to select and execute options, other than the first option, only upon command from the ARPV operator. The first option, which would be programmed for automatic execution in the absence of an operator command, would be to transmit the video taped imagery at normal bandwidth while proceeding at terrain following altitude to the next target. The second option would be a slow readout of the taped imagery for a reduced bandwidth transmission for better antijam performance, if the first option does not produce satisfactory imagery at the ARPV control unit. The third option would be the same as the second except that the ARPV would climb to a much higher altitude to improve transmission. The second and third options would only be executed upon command from the ARPV control unit. Only at the control unit could the quality of the received imagery be assessed and a determination made if the need was great enough for the much higher risk to the ARPV of the higher altitude flight of option three.

Segments 10 and 11 of this mission are functionally the same as segments 8 and 9 except that the sensor would be an infrared line scanner to provide radiation imagery in the 8- to 14-micrometer wavelength band. A navigation checkpoint near the second target would be used to update position for target coverage flight path adjustment. The same options and constraints discussed above would apply to data linking of imagery to the ARPV control station. Segments 12 and 13 would also be functionally the same as segments 8 and 9, including use of the same sensor. These segments would be repeated for each assigned reconnaissance point target.

If the target were a line target, such as a railroad or highway, the functions would be the same as those for segments 8 and 9 except for navigation. The final checkpoint would be selected to make alignment with the line target relatively easy. Also, navigation maneuvers would have to be performed to keep the ARPV ground track along the line target wherever there are curves in the railroad or highway.

Segment 14 starts when the ARPV passes its last assigned target or the end of the line target. The program for return to the FEBA is selected, the vehicle returns to terrain following altitude, and checkpoint navigation is used to follow the programmed ground track. RF navigation is used as an additional navigation input when it becomes available. Imagery of the last target can be data linked to the control unit during this segment, if required. Even though data linking of imagery to the control unit is included in the functions after each target, it should not be assumed that this function will be used very often. There will be relatively few targets where timely imagery is critical enough to require this. For most ARPV reconnaissance sorties, data linking of imagery will not be used. This will cut down interference and bandwidth assignment problems for the few sorties which do require it.

Segments 15 through 20 are the same as segments 11 through 16 for the strike mission which will not be repeated here. They involve identification of the ARPV on crossing the FEBA, return to base, transfer of control, recovery and postflight checkout and maintenance.

Figure A-4 shows the approximate reconnaissance mission profile. The altitudes and ranges are representative of the expected conditions and will vary considerably for each sortie. An increase in altitude is shown over each target to emphasize the functions to be performed. However, the navigation accuracy of the ARPV and sensor V/H capability and lateral coverage should be such that pullup above penetration altitude should seldom be necessary.

C. ARPV ELECTRONIC WARFARE MISSION SCENARIO

The electronic warfare (EW) mission has a simpler flight profile than the strike and reconnaissance missions. However, the EW functions are more complex due to the fact that several ARPVs are engaged simultaneously in the same mission, that they perform their mission over an extended period of time, and that for active jamming, some options must be provided along with some means of controlling the options.

For mission definition it is assumed that each EW ARPV carries internally the dispenser mechanism and bulk chaff load of an ALE-38 chaff dispenser pod. It is also assumed that the active EW equipment consists of the equivalent of an ALQ-131 jammer and an ALR-46 receiver for determining threats to be jammed and the priority for each threat.

A typical EW mission would consist of laying down a chaff corridor to cover a multiple aircraft strike by manned aircraft on a target at least 50 to 100 nautical miles beyond the FEBA and providing active jamming support for the manned strike in the target area.

To lay down a chaff corridor large enough and dense enough to cover a manned aircraft strike force will require at least four ARPVs dispensing at a rate which would exhaust their chaff in 75 to 100 miles. Thus, two or more sets of four ARPVs will be required for chaff dispensing. For an effective chaff corridor, lateral spacing of the ARPVs must be controlled so as to avoid gaps in the coverage while making it wide enough to cover the manned aircraft formation. Along-track spacing is not as critical as lateral spacing but must be controlled within reasonable limits. It may be feasible to maintain the required spacing with the basic ARPV navigation system using closely aligned preprogrammed flight paths. If not, some form of loose formation stationkeeping will be required. It should be noted that when using DME or JTIDS radio navigation, relative position within a loose formation can be measured. Also, GPS accuracy will be more than enough to maintain the required spacing using programmed navigation. Therefore, loose formation spacing should only be a problem when radio navigation is not feasible due to enemy jamming. For EW ARPVs operating at medium to high altitude, there should not be long periods when radio navigation is not possible.

Figures A-5 and A-6 show the EW mission segment sequence and summary and the EW mission flight profile and numbered mission segments. The segments are numbered to permit correlation of the segments on the two figures and the following discussion of the segments. The discussion will primarily be about a single ARPV but the mission will be conducted by sets of four or five ARPVs. For the range shown on Figure A-6, at least three sets of chaff dispensing vehicles will be required. This is based on a 75- to 100-mile corridor for each set and a corridor at least 240 miles long. The 240 miles is based on using different ingress and egress paths for the manned aircraft.

The ARPVs are launched over a short span of time and form into three sets based on preplanned navigation programs. This is accomplished during segment 3 under the control of the launch and recovery unit. This avoids complicating the task of the ARPV combat operations unit, which may have to handle several ARPV missions simultaneously. This multiaircraft ARPV mission is similar to the single-sortie missions in that enroute cruise (segment 5) and subsequent segments are based upon programmed, automatic functions. These are monitored by operators at the COU but command inputs to change programmed actions will be required only under unusual circumstances.

An example of the necessity for an operator commanded input would be the corrective action if one of the chaff dispensers fails in segment 6. In this segment, each of the ARPV aircraft is following a programmed flight path. However, to prevent gaps in the chaff corridor due to navigation errors, the ARPVs also monitor relative position with respect to the ARPV designated as the flight-path controller. If the programmed flight paths result in lateral spacing being more than 200 to 300 feet from optimum, or the along-track spacing being off by more than 2,000 to 4,000 feet, the relative position data is used to correct the relative position. This will prevent gaps in the basic coverage with all chaff dispensers operating properly, but not if one of them malfunctions. When the operator receives a signal from onboard test equipment indicating malfunction of a chaff dispenser, the other ARPVs do not receive this signal. The operator must then select the desired option to compensate for the missing chaff. This will require commanding the remaining ARPVs to begin following optional navigation programs to eliminate the gap in coverage. These optional navigation programs will already be stored in the navigation computer of each ARPV and the operator only needs to command a change from the primary to the appropriate optional program. If there is a spare ARPV in the formation, the operator can command it to begin dispensing chaff and fly the flight path of the ARPV with the malfunctioning dispenser. In this situation, the remaining ARPVs do not make any changes.

The first set of ARPVs performs segments 6 and 7 and begins laying down a chaff corridor just prior to the FEBA and the other two sets of ARPVs follow the corridor. Since the ARPVs are flying at altitude, they use their active EW capability to counter any detected radar threats. This is particularly true of the lead set which has no chaff cover. When the first set of ARPVs exhausts its chaff, the second set assumes the lead and continues laying chaff. Upon reaching the target area all the ARPVs perform the functions of segment 8. They loiter in the area, following programmed flight paths, and provide active jamming support against all assigned threats.

For segment 9 the ARPVs which still have chaff aboard are programmed to depart the target area while the strike is in progress to lay down an egress chaff corridor. The remaining

AD-A041 502 TEXAS INSTRUMENTS INC DALLAS EQUIPMENT GROUP F/G 1/3
SYSTEM AVIONIC ARCHITECTURES FOR RPVS.(U)
APR 77 R ALLEN, L CHAMBERLIN, J EARLY F33615-76-C-1215
UNCLASSIFIED AFAL-TR-76-245 NL

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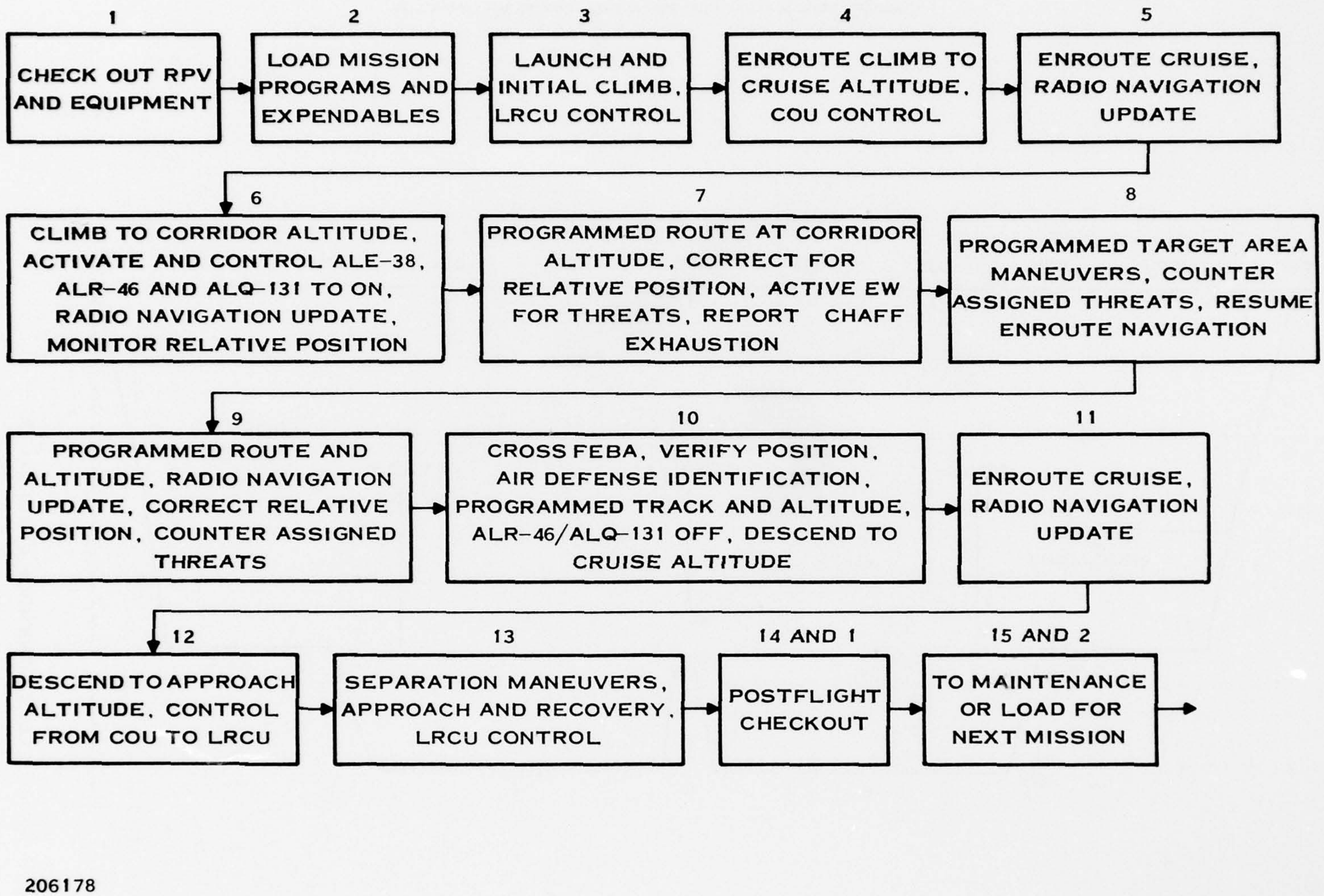

Figure A-5. EW Mission Segment and Sequence Summary

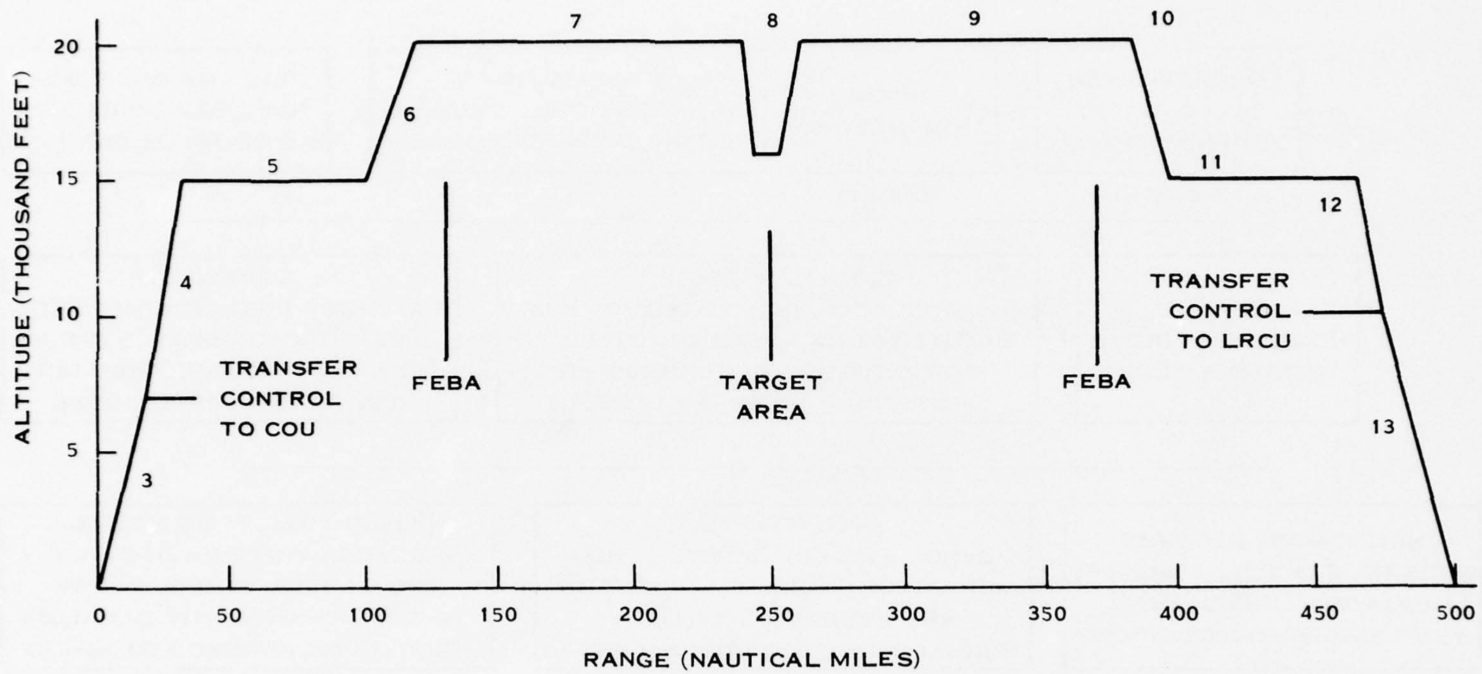

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Figure A-6. EW Mission Profile and Numbered Mission Segments *b. Checkout items when reconfiguring ARPV from EW to strike configuration.*

Remove chaff dispenser.

Remove active jammers.

Remove threat warning subsystem.

Remove EW dedicated processors.**

Install weapon handling equipment.

Install weapon delivery (WD) dedicated processor.**

Install checkpoint navigation sensor and dedicated processor.

Change processor resident programs.

- Remove EW programs.
- Read in WD programs.
- Read in checkpoint navigation program.
- Read in weapon handling program (can be part of WD program).

c. Additional checkout when ARPV is brought up from storage. Start engines and check out:

Engine data from idle through military power

Engine control response to command inputs, including shutdown

Hydraulic system performance

Electrical power generation and control

Flight control actuation and response to command inputs.

2. Functions for Segment 2, Load Mission Programs and Expendables

Load weapons and check out interface with weapon control processor.

Load fuel, oil if required (no processing functions required for this).

Load and read back mission program (ground track, altitude profile, communication data, equipment operation points, etc.).

Load and read back weapon operation program.

Load and read back mission weapon delivery program.

Load and read back programs for required options (recall, alternate target, alternate sensor, alternate route home, etc.).

Load radiation target data.

Load navigation checkpoint signatures.

**If applicable

ARPVs provide active EW support for the manned aircraft while these manned aircraft are following the egress chaff corridor. These active EW ARPVs will be programmed to remain outside the corridor to avoid conflict with the manned aircraft. They will have navigation programs which keep them in loose formation for mutual EW protection against home-on-jam tactics.

Upon crossing the FEBA, each set of ARPVs will individually perform the functions of segment 10. Each set will be following a navigation program which should result in separate groups of four or five ARPVs. These groups will be spaced far enough apart along track to permit recovery of each group before the next is ready to begin approach and recovery. If not, the combat operations unit will need to command any maneuvers required to correct the spacing during segment 11, prior to descent to approach altitude.

Once the spacing is adequate, each set of ARPVs descends to approach altitude and control is transferred to the launch and recovery control unit (segment 12). The LRCU monitors the automatic performance of maneuvers to separate each set of ARPVs for individual recovery and commands corrections if necessary. Following this, the remainder of segments 13, 14, and 15 are the same as segments 14, 15, and 16 for the strike mission, and will not be repeated here.

Figure A-6 shows a typical flight profile for an EW mission with the flight segments numbered to correspond to Figure A-5. The altitudes and ranges are only representative values as are the breakpoints between segments. The segments shown will require performance of all functions likely to be required on an EW mission.

II. ARPV MISSION FUNCTIONS

A. AVIONIC FUNCTIONS FOR STRIKE MISSION

1. *Functions for Segment 1, Checkout RPV and Equipment*

a. Normal checkout items

- Initialize Processors
- Core and mission processor performance tests
- Core and mission processor resident program tests
- Electronic subsystem tests
  - Communication subsystems
  - Navigation subsystems
  - Status monitoring subsystem
- Electrical power subsystem*
- Flight control subsystem*
- Engine control subsystem*
- Vehicle flight configuration subsystem.*

* Checkout to extent feasible without engine running.

3. **Functions for Segment 3, Launch and Initial Climb**

For catapult launch, attach catapult cable, wheels down.

Verify narrowband data link (NBDL) contact with, and ARPV control by, Launch and Recovery Control Unit (LRCU).

Align INS and acquire GPS navigation signals.

Start engine and verify normal operation of electrical, hydraulic and other subsystems.

Set flight configuration for launch using LRCU and mission control program input commands.

Advance engine to full power and activate launch mechanism.

Automatic flight control to maintain attitude until airspeed and rate of climb buildup.

Automatic flight configuration management based on airspeed and rate of climb.

When configuration is clean and airspeed is adequate, transition to programmed flight profile and ground track.

Adjust engine to climb power and maintain programmed airspeed.

Monitor and control all other subsystems on programmed basis and report status and position over NBDL.

At preplanned enroute point, verify communication with Combat Operations Unit (COU) and transfer control from LRCU to COU.

4. **Functions for Segment 4, Enroute Climb**

Maintain climb power and airspeed.

Follow programmed ground track using INS.

Update INS continuously with GPS navigation.

Monitor and report position and status of all subsystems to COU.

Level off at programmed altitude.

Adjust to cruise power when cruise airspeed is reached.

5. **Functions for Segment 5, Enroute Cruise**

Maintain cruise altitude.

Maintain cruise airspeed.

Follow programmed ground track using INS.

Update INS continuously with GPS navigation.

Establish and verify operation of wideband data link (WBDL). Switch to standby after verification.

Reduce power and begin descent to penetration altitude.

Monitor and report status of all subsystems to COU.

6. **Functions for Segment 6, Descend to Penetration Altitude**

Maintain descent airspeed schedule.

Maintain descent power.

Follow programmed ground track using INS.

Update INS continuously with GPS navigation.

Switch low-altitude equipment from standby to on.

Use radar altimeter to level off at penetration altitude.

Increase power to penetration cruise power.

Transition to terrain following.

Update INS at programmed locations with checkpoint navigation.

Monitor and report status of all subsystems.

7. **Functions for Segment 7, Penetration to Target Area**

Maintain terrain following at penetration altitude.

Adjust power to maintain penetration airspeed.

Follow programmed ground track using INS.

Update INS position over each programmed checkpoint.

Switch target acquisition and weapon delivery sensors from standby to on.

Switch WBDL to on and verify image transfer.

Activate and/or arm weapons and weapon release subsystem at programmed location or time to go.

Monitor and report status of all subsystems.

8. **Functions for Segments 8 and 9, Checkpoint Update, Pull Up, Target Acquisition and Weapon Delivery (TA&WD)**

Maintain terraim following at penetration altitude.

Follow programmed ground track using INS.

Initiate sensor pointing using INS and target position.

Update INS position over final checkpoint inbound to the target.

At programmed distance from target based on INS output, pull up and follow programmed profile for target acquisition and weapon delivery.

Adjust power to maintain airspeed.

Acquire and track target on radiation sensor.

Switch to radiation sensor data for weapon delivery when it becomes more accurate than INS data.

Continue sensor pointing using INS position or radiation sensor azimuth and elevation.

Compute three dimensional weapon delivery maneuver commands using INS and target positions and weapon ballistics.

Execute three-dimensional weapon delivery computations using INS and target positions.

Compute weapon release points and after receipt of operator release approval, release weapons when within proximity limits.

Monitor and report status of all subsystems.

9. Functions for Segment 10, Return to Penetration Altitude and FEBA

Establish and maintain descent profile.

Adjust power to maintain descent airspeed.

Follow programmed ground track using INS.

Use radar altimeter to level off at penetration altitude.

Increase power to penetration cruise power.

Transition to terrain following.

Update INS at programmed checkpoint locations.

Return TA&WD sensors and WBDL to standby.

On approaching FEBA, resume radio navigation.

Monitor and report status of all subsystems.

10. Functions for Segments 11 and 12, Transition Past FEBA, Climb and Enroute Cruise

INS position update over ground checkpoint.

Operate IFF as programmed.

Adjust engine to climb power.

Follow climb airspeed schedule.

Execute programmed identification maneuvers.

Update INS continuously with GPS navigation.

Level off at and hold cruise altitude.

Follow programmed ground track using INS.

Adjust engine to maintain cruise airspeed.

Monitor and report status of all subsystems.

11. Functions for Segment 13, Descent to Approach Altitude

Follow programmed ground track using INS.

Continuously update INS using radio navigation.

Descent and approach equipment from standby to on. Verify operation.

Reduce power and follow descent airspeed schedule.

At programmed location, verify communication with LRCU and transfer control from COU to LRCU.

Transition from enroute to approach radio navigation update of the INS.

Execute programmed delay turns or orbits upon LRCU command.

Monitor and report status of all subsystems to LRCU.

12. Functions for Segment 14, Approach and Recovery

Reduce power and slow descent rate to reduce airspeed.

Follow programmed approach ground path using INS and MLS.

Continuously update INS using MLS or transition to MLS for approach control.

At programmed airspeed, extend landing gear, flaps and barrier engagement hook.

Adjust engine power to maintain programmed airspeed and descent rate.

Follow programmed ground track and flight path using approach RF navigation.

Use radar altimeter data as programmed.

Follow airspeed, position, and altitude schedule to touchdown.

Shut down engine on touchdown or barrier hook engagement.

Turn off core and mission equipment.

Monitor and report status of all subsystems to LRCU.

13. Functions for Segment 15, Postflight Checkout

a. Normal checkout items

Same as for segment 1.

b. Checkout items when reconfiguring ARPV from strike to EW configuration

Remove weapon handling equipment.

Remove WD dedicated processor.**

Remove checkpoint navigation sensor and dedicated processor.**

Install chaff dispensers and active jammers.

Change processor programs.

Remove strike and checkpoint navigation programs.

Read in active-jamming program.

Read in chaff-dispensing program.

Read in navigation program, including stationkeeping.

**If applicable

14. Functions for Segment 16, Load for Next Mission

Load chaff and arm dispenser.

Load fuel, oil, etc.

Load and read back mission program (ground track, altitude profile, stationkeeping for chaff dispensing, communication data, equipment operating points, etc.).

Load and read back chaff dispensing and active jamming programs.

Load and read back programs for required options (recall, alternate chaff schedules, alternate routes home, etc.).

B. AVIONIC FUNCTIONS FOR ARPV RECONNAISSANCE MISSION

1. Functions for Segment 1, Check Out RPV and Equipment

a. Normal checkout items

Initialize processors

Core and mission processor performance tests

Core and mission processor resident program tests

Electronic subsystem tests

- Communication subsystems
- Navigation subsystems
- Status monitoring subsystem

Sensor subsystem

Electrical power subsystem*

Flight control subsystem*

Engine control subsystem*

Vehicle flight configuration subsystem.*

b. Check out items when reconfiguring ARPV from EW to reconnaissance configuration.

Remove chaff dispenser.

Remove active jammers.

Remove threat warning subsystem.

Remove EW dedicated processors.**

Install sensor subsystem.

Install checkpoint navigation sensor and dedicated processor.

Change processor resident programs.

- Remove EW programs.

*Check out to extent feasible without engine running.

**If applicable.

Read in checkpoint navigation program.

Read in sensor program, including imagery transmission requirements.

c. *Additional checkout when ARPV is brought up from storage. Start engines and check out.*

Engine data from idle through military power

Engine control response to command inputs, including shutdown

Hydraulic system performance

Electrical power generation and control

Flight control actuation and response to command inputs.

2. **Functions for Segment 2, Load Mission Programs and Expendables**

Load sensor film and recording tape and check out interface with control processor.

Load fuel, oil if required (no processing functions required for this).

Load and read back mission program (ground track, altitude profile, communication data, equipment operation points, etc.).

Load and read back sensor operation program.

Load and read back programs for required options (recall, alternate targets, alternate sensor, alternate route home, etc.).

Load navigation checkpoint signatures.

3. **Functions for Segment 3, Launch and Initial Climb**

For catapult launch, attach catapult cable, wheels down.

Verify narrowband data link (NBDL) contact with, and ARPV control by, Launch and Recovery Control Unit (LRCU).

Align INS and acquire GPS navigation signals.

Start engine and verify normal operation of electrical, hydraulic and other subsystems.

Set flight configuration for launch using LRCU and mission control program input commands.

Advance engine to full power and activate launch mechanism.

Automatic flight control to maintain attitude until airspeed and rate of climb build up.

Automatic flight configuration management based on airspeed and rate of climb.

When configuration is clean and airspeed is adequate, transition to programmed flight profile and ground track.

Adjust engine to climb power and maintain programmed airspeed.

Monitor and control all other subsystems on programmed basis and report status and position over NBDL.

At preplanned enroute point, verify communication with Combat Operations Unit (COU) and transfer control from LRCU to COU.

4. **Functions for Segment 4, Enroute Climb**

Maintain climb power and airspeed.

Follow programmed ground track using INS.

Update INS continuously with GPS navigation.

Monitor and report position and status of all subsystems to COU.

Level off at programmed altitude.

Adjust to cruise power when cruise airspeed is reached.

5. **Functions for Segment 5, Enroute Cruise**

Maintain cruise altitude.

Maintain cruise airspeed.

Follow programmed ground track using INS.

Update INS continuously with GPS navigation.

Establish and verify operation of wideband data link (WBDL). Switch to standby after verification.

Reduce power and begin descent to penetration altitude.

Monitor and report status of all subsystems to COU.

6. **Functions for Segment 6, Descend to Penetration Altitude**

Maintain descent airspeed schedule.

Maintain descent power.

Follow programmed ground track using INS.

Update INS continuously with GPS navigation.

Switch low altitude equipment from standby to on.

Switch reconnaissance sensors from off to standby.

Use radar altimeter to level off at penetration altitude.

Increase power to penetration cruise power.

Transition to terrain following.

Update INS at programmed locations with checkpoint navigation.

Monitor and report status of all subsystems.

7. **Functions for Segment 7, Penetration to Target Area No. 1**

Maintain terrain following at penetration altitude.

Adjust power to maintain penetration airspeed.

Follow programmed ground track using INS.

Update INS position over each programmed checkpoint.

Monitor and report status of all subsystems.

8. **Functions for Segment 8, Checkpoint Update, Pull Up, Imagery Collection for Target No. 1**

Maintain terrain following at penetration altitude.

Follow programmed ground track using INS.

Update INS position over final checkpoint inbound to the target.

At programmed distance from target based on INS output, pull up and follow programmed profile for imagery collection and recording.

Adjust power to maintain airspeed.

At programmed point, switch sensor for target No. 1 from standby to on and follow programmed ground track and profile for target No. 1.

Monitor and report position and status of all subsystems.

9. **Functions for Segment 9, Penetration to Target No. 2**

At programmed point, switch sensors to standby.

Establish and maintain descent profile.

Adjust power to maintain descent airspeed.

Level off and transition to terrain following.

Follow ground track using INS.

Update INS over each programmed checkpoint.

On command, retrieve taped imagery of target No. 1 and transmit via WBDL.

Monitor and report position and status of all subsystems.

10. **Functions for Segment 10, Checkpoint Update, Pull Up, Imagery Collection for Target No. 2**

Maintain terrain following at penetration altitude.

Follow programmed ground track using INS.

Update INS position over final checkpoint on inbound leg for target No. 2.

At programmed distance from target based on INS output, pull up and follow programmed profile for imagery collection and recording.

Adjust power to maintain airspeed.

At programmed point, switch sensor for target No. 2 from standby to on and follow programmed ground track and profile for target No. 2.

Monitor and report position and status of all subsystems.

11. Functions for Segments 11, 12 and 13, Penetration to Targets No. 3, 4, Etc., Checkpoint Update, Pull Up and Imagery Collection

Repeat functions for segments 9 and 10 for each assigned reconnaissance target.

12. Functions for Segment 14, Return to Penetration Altitude and FEBA

Establish and maintain descent profile.

Adjust power to maintain descent airspeed.

Follow programmed ground track using INS.

Use radar altimeter to level off at penetration altitude.

Increase power to penetration cruise power.

Transition to terrain following.

Update INS at programmed checkpoint locations.

Return reconnaissance sensors and WBDL to off.

On approaching FEBA, resume radio navigation.

Monitor and report position and status of all subsystems.

13. Functions for Segments 15 and 16, Transition Past FEBA, Climb and Enroute Cruise

INS position update over ground checkpoint.

Operate IFF as programmed.

Adjust engine to climb power.

Follow climb airspeed schedule.

Execute programmed identification maneuvers.

Update INS continuously with GPS navigation.

Level off at and hold cruise altitude.

Follow programmed ground track using INS.

Adjust engine to maintain cruise airspeed.

Monitor and report position and status of all subsystems.

14. **Functions for Segment 17, Descent to Approach Altitude**

Follow programmed ground track using INS.

Continuously update INS using GPS.

Descent and approach equipment from standby to on. Verify operation.

Reduce power and follow descent airspeed schedule.

At programmed location, verify communication with LRCU and transfer control from COU to LRCU.

Transition from enroute to approach radio navigation update of the INS.

Execute programmed delay turns or orbits upon LRCU command.

Monitor and report status of all subsystems to LRCU.

15. **Functions for Segment 18, Approach and Recovery**

Reduce power and slow descent rate to reduce airspeed.

Follow programmed approach ground path using INS and MLS.

Continuously update INS using MLS or transition to MLS for approach control.

At programmed airspeeds, extend landing gear, flaps and barrier engagement hook.

Adjust engine power to maintain programmed airspeed and descent rate.

Follow programmed ground track and flight path using approach RF navigation.

Use radar altimeter data as programmed.

Follow airspeed position and altitude schedule to touchdown.

Shut down engine on touchdown or barrier hook engagement.

Turn off core and mission equipment.

Monitor and report status of all subsystems to LRCU.

16. **Functions for Segments 19 and 20**

Same as segments 1 and 2.

C. ELECTRONIC WARFARE MISSION

1. **Functions for Segment 1, Checkout RPV and Equipment**

a. ***Normal checkout items***

Initialize processors

Core and mission processor performance tests

Core and mission processor resident program tests

Electronic subsystems tests

Communication subsystems

Navigation subsystems

Status monitoring subsystem

Electrical power subsystem*

Flight control subsystem*

Engine control subsystem*

Vehicle flight configuration subsystem.*

b. ***Checkout items when reconfiguring ARPV from strike to EW configuration.***

Remove weapon handling equipment.

Remove weapon delivery dedicated processors.**

Install chaff dispenser and active jamming.

Install EW dedicated processor.

Remove checkpoint navigation sensor and dedicated processor.**

Change processor resident programs.

Read in EW programs.

Remove WD programs.

Remove checkpoint navigation program.

Remove weapon handling program.

c. ***Additional checkout when ARPV is brought up from storage. Start engines and checkout.***

Engine data from idle through military power

Engine control response to command inputs, including shutdown

Hydraulic system performance

Electrical power generation and control

Flight control actuation and response to command inputs.

2. Functions for Segment 2, Load Mission Programs and Expendables

Load chaff and set dispenser controls.

Load fuel, oil if required (no processing functions required for this).

Load and read back mission program (ground track, altitude profile, communication data, equipment operation points, etc.).

Load and read back jammer chaff-dispensing schedule, including alternates to cover other ARPV losses.

*Checkout to extent feasible without engine running.
**If applicable.

Load and read back programs for required options (recall, alternate target, alternate sensor, alternate route home, etc.).

Load and read back programs for required flight path adjustments to permit loose formation join up under Launch and Recovery Unit (LRCU) control.

3. **Functions for Segment 3, Launch and Initial Climb**

For catapult launch, attach catapult cable, wheels down.

Verify narrowband data link (NBDL) contact with, and ARPV control by, Launch and Recovery Control Unit (LRCU).

Align INS and acquire GPS navigation signals.

Start engine and verify normal operation of electrical, hydraulic and other subsystems.

Set flight configuration for launch using LRCU input commands.

Advance engine to full power and activate launch mechanism.

Automatic flight control to maintain attitude until airspeed and rate of climb build up.

Automatic flight configuration management based on airspeed and rate of climb.

When configuration is clean and airspeed is adequate, transition to programmed flight profile and ground track.

Adjust engine to climb power and maintain programmed airspeed.

Monitor and control all other subsystems on programmed basis and report status and position over NBDL.

Perform programmed maneuvers in response to LRCU commands to join up in loose formation with other EW ARPVs.

At preplanned enroute point, verify communication with Combat Operations Unit (COU) and transfer control from LRCU to COU.

4. **Functions for Segment 4, Enroute Climb**

Maintain climb power and airspeed.

Follow programmed ground track using INS.*

Update INS continuously with GPS navigation.

Monitor and report position and status of all subsystems to COU.

Level off at programmed altitude.

Adjust to cruise power when cruise airspeed is reached.

Adjust power as required to maintain along track loose formation.**

*Individual ground tracks will be preprogrammed to provide desired spacing for dispensing chaff corridor.

**Along-track position will be maintained by designating one ARPV as lead aircraft. The other ARPVs will monitor its position reports, compare their along-track position with the lead position and adjust power (and airspeed) to correct along-track position.

5. **Functions for Segment 5, Enroute Cruise**

Maintain cruise altitude.

Maintain cruise airspeed.

Follow programmed ground track using INS.

Update INS continuously with GPS navigation.

Maintain along-track loose formation.

Increase power and begin climb to chaff-corridor altitude.

Monitor and report position and status of all subsystems to COU.

6. **Functions for Segment 6, Climb to Corridor Altitude and Laying Chaff Corridor**

Maintain climb schedule.

Maintain climb power with adjustments to maintain along-track loose formation.

Follow programmed ground track using INS.

Update INS continuously with GPS navigation.

Level off at corridor altitude.

Adjust to cruise power when cruise airspeed is reached.

Maintain along-track loose formation.

Switch ALE-38, ALR-46 and ALQ-131 from standby to on.

At programmed location, activate ALE-38 and begin laying chaff corridor.

Monitor and report position and status of all subsystems.

7. **Functions for Segment 7, Laying Chaff Corridor**

Maintain corridor altitude.

Follow programmed ground track using INS.

Update INS continuously with GPS navigation.

Maintain cruise power adjusted to maintain along-track loose formation.

Continue chaff dispensing.

Report chaff exhaustion.

If programmed to do so, activate ALQ-131 in response to specified threats.

Monitor and report position and status of all subsystems.

8. Functions for Segment 8, Target Area Support Jamming

Maintain corridor altitude and follow programmed ground track to target area.

At programmed location begin area jamming following mission jamming program.

Perform target area maneuvers using mission altitude and ground track program.

At programmed time or location, resume enroute navigation along egress chaff corridor.

Operate jammer in accordance with mission and mission jamming programs.

Update INS continuously with GPS.

When on target departure ground track, adjust cruise power to maintain along-track loose formation.

Monitor and report position and status of all subsystems.

9. Functions for Segment 9, Return to FEBA

Maintain corridor altitude.

Follow programmed ground track using INS.

Update INS continuously with GPS.

Adjust power to maintain along-track loose formation.

At programmed location, discontinue area jamming.

If programmed to do so, activate ALQ-131 in response to specified threats.

Monitor and report position and status of all subsystems.

10. Functions for Segments 10 and 11, Transition Past FEBA and Cruise to Destination

Operate IFF as programmed.

Perform programmed identification maneuvers.

ALR-46 and ALQ-131 to standby or off.

Reduce power and follow descent airspeed schedule.

Level off at cruise altitude and adjust engine to cruise power.

Follow programmed ground track using INS.

Update INS continuously with GPS.

Adjust power to maintain along-track loose formation.

Monitor and report position and status of all subsystems.

11. **Functions for Segment 12, Descent to Approach Altitude and Separation Maneuvers**

Follow programmed ground track using INS.

Continuously update INS using GPS.

Descent and approach equipment from standby to on. Verify operation.

Reduce power and follow descent airspeed schedule.

At programmed location, verify communication with LRCU and transfer control from COU to LRCU.

Transition from enroute to MLS update of the INS.

Execute programmed maneuvers for flight separation.

Execute additional programmed delay turns or orbits upon LRCU command.

Monitor and report position and status of all subsystems to LRCU.

12. **Functions for Segment 13, Approach, Recovery, and Postflight Checkout**

Reduce power and slow descent rate to reduce airspeed.

Follow programmed approach ground path using INS and MLS.

Continuously update INS using MLS or transition to MLS for approach control.

At programmed airspeeds, extend landing gear, flaps, and barrier engagement hook.

Adjust engine power to maintain programmed airspeed and descent rate.

Follow programmed ground track and flight path using MLS navigation.

Use radar altimeter TFR data as programmed.

Follow airspeed, position, and altitude schedule to touchdown.

Shut down engine on touchdown or barrier hook engagement.

Turn off core and mission equipment.

Monitor and report status of all subsystems to LRCU.

Repeat normal checkout items from segment 1.

APPENDIX B

ARPV EQUIPMENT AND SIGNAL LIST

APPENDIX B

ARPV EQUIPMENT AND SIGNAL LIST

This appendix contains the assumed ARPV generic equipment and associated signal list.

Table B-1 lists the equipment complement needed for the various missions formulated in Appendix A.

Table B-2 is a list of input signals required and output signals generated by the equipment shown in Table B-1. Not all signals are required (either input or output) and not all equipment operates during all mission segments. For example, the IMU operates continuously in contrast with the MLS which operates only during landing maneuvers.

The column labeled "No. of Bits" in Table B-1, indicates the accuracy of the messages in terms of bits. For example Normal Band Data Link (NBDL) requires 1 bit for power on/off control, 1 bit for mode set (operate/standby), 12 bits for frequency select, 2 bits for transmit/receive command, N X 16 bits for the messages to be transmitted (with N the number of words), N X 16 bits for messages received, and less than 16 bits for status report. Some of these messages flow via the data bus and some are generated internally by the subsystem service algorithm assigned to this particular piece of equipment, depending on the architecture considered.

TABLE B-1. ARPV GENERIC EQUIPMENT LIST

Equipment	Mission: Strike	Recce	EW
NBDL (JTIDS)	X	X	X
IMU	X	X	X
GPS	X	X	X
Radar Altimeter	X	X	X
Remote Compass	X	X	X
Air Data	X	X	X
MLS	X	X	X
Flight Control	X	X	X
Engine Control	X	X	X
IFF	X	X	X
FLIR	X		
Radiation Sensor	X		
Weapon Station	X		
Checkpoint Update (TERCOM)	X	X	
WBDL (Video)	X	X	
IR Line Scanner		X	
Photo Camera		X	
Chaff Dispenser			X
Threat Warning Receiver			X
Active Jammer			X

TABLE B-2. ARPV EQUIPMENT SIGNAL LIST

Equipment	Signal	In/Out	Iteration Rate/Second	Number of Bits
NBDL T/R*	Power On	In	1	1
NBDL T/R	Mode	In	1	1
NBDL T/R	Frequency	In	1	12
NBDL T/R	Transmit/Receive	In	16	2
NBDL T/R	Input Data	In	16	X 16
NBDL T/R	Output Data	Out	16	X 16
NBDL T/R	Status	Out	1	<16
WBDL**	Power On	In	1	1
WBDL	Operate Mode	In	1	1
WBDL	Frequency Band	In	1	10
WBDL	Frequency	In	1	12
WBDL	Antijam Mode	In	1	3
WBDL	Frame Rate	In	1	5
WBDL	Status	Out	1	<16
IFF	Power On	In	1	1
IFF	Operate Mode	In	1	1
IFF	Mode Select	In	4	3
IFF	Code Select	In	4	8
IFF	Indent.	In	4	1
IFF	Altitude	In	1	12
IFF	Status	Out	1	<16
MLS	Power On	In	1	1
MLS	Mode	In	1	1
MLS	Frequency	In	1	<16
MLS	DME On/Off	In	1	1
MLS	TC Azimuth	Out	16	16
MLS	TC Elevation	Out	16	16
MLS	TC Range	Out	16	16
MLS	Status	Out	1	<16
Remote Compass	Ex Power On	In	1	1
Remote Compass	Magnetic Heading	Out	16	12
Remote Compass	Status	Out	1	<16
IMU	Power On	In	1	1
IMU	Pitch Rate (B)	Out	32	16
IMU	Roll Rate (B)	Out	32	16
IMU	Yaw Rate (B)	Out	32	16
IMU	Pitch Axis Acceleration (B)	Out	32	16
IMU	Roll Axis Acceleration (B)	Out	32	16
IMU	Yaw Axis Acceleration (B)	Out	32	16
IMU	Status	Out	1	<16
IMU	Acceleration Scale Change	Out	32	8
GPS	Power On	In	1	1
GPS	Time	In	1	15
GPS	Range	Out	50	4 X 16
GPS	Range Rate	Out	50	4 X 16
GPS	Status	Out	1	<16
GPS	Latitude	In	1	9
GPS	Longitude	In	1	11

*Narrowband data link-transmit/receive (JTIDS)

**Wideband data link

TABLE B-2. ARPV EQUIPMENT SIGNAL LIST *(Continued)*

Equipment	Signal	In/Out	Iteration Rate/Second	Number of Bits
Radar Altimeter	Power On	In	1	1
Radar Altimeter	Mode	In	1	1
Radar Altimeter	Altitude	Out	32	10
Radar Altimeter	Status	Out	1	<16
Checkpoint Update (TERCOM)	Power On	In	1	1
Checkpoint Update (TERCOM)	Mode	In	8	2
Checkpoint Update (TERCOM)	Sensor Activate	In	8	2
Checkpoint Update (TERCOM)	Checkpoint data	Out	32	4
Checkpoint Update (TERCOM)	Time	Out	32	16
Checkpoint Update (TERCOM)	Status	Out	1	<16
Air Data	Power On	In	1	1
Air Data	Total Temperature	Out	4	8
Air Data	Total Pressure	Out	4	11
Air Data	Static Pressure	Out	4	11
Air Data	Status	Out	1	<16
Flight Control	Power On	In	1	1
Flight Control	Elevator Movement	In	32	9
Flight Control	Aileron Movement	In	32	9
Flight Control	Rudder Movement	In	32	9
Flight Control	Status	Out	1	<16
Engine and Engine Control	Power On	In	1	1
Engine and Engine Control	Throttle Position	In	16	8
Engine and Engine Control	RPM	Out	16	8
Engine and Engine Control	TOT	Out	4	8
Engine and Engine Control	TOP	Out	4	8
Engine and Engine Control	Overheat	Out	4	1
Engine and Engine Control	Fuel Pressure	Out	4	8
Engine and Engine Control	Fuel Flow	Out	4	8
Engine and Engine Control	Status	Out	1	<16
Chaff Dispenser	Power On	In	1	1
Chaff Dispenser	Mode	In	1	1
Chaff Dispenser	Type Dispenser	In	1	1
Chaff Dispenser	Pulse Rate	In	1	8
Chaff Dispenser	Pulse Interval	In	1	8
Chaff Dispenser	Chaff Exhausted	Out	1	1
Chaff Dispenser	Status	Out	1	<16

TABLE B-2. ARPV EQUIPMENT SIGNAL LIST (Continued)

Equipment	Signal	In/Out	Iteration Rate/Second	Number of Bits
FLIR and Gimbal	Power On	In	1	1
FLIR and Gimbal	Mode	In	1	2
FLIR and Gimbal	Gimbal Store	In	4	1
FLIR and Gimbal	LOS Point	In	4	1
FLIR and Gimbal	Azimuth Angle	In	16	13
FLIR and Gimbal	Elevation Angle	In	16	12
FLIR and Gimbal	FOV Select	In	4	4
FLIR and Gimbal	Gain	In	4	2
FLIR and Gimbal	Focus	In	4	2
FLIR and Gimbal	Reticle	In	4	2
FLIR and Gimbal	Cooling	Out	1	1
FLIR and Gimbal	Not Ready	Out	1	1
FLIR and Gimbal	Standby	Out	1	1
FLIR and Gimbal	Operate	Out	1	1
FLIR and Gimbal	Status	Out	1	<16
FLIR and Gimbal	Azimuth	Out	4	6
FLIR and Gimbal	Elevation	Out	4	6
Radiation Sensor	Power On	In	1	1
Radiation Sensor	Mode	In	1	3
Radiation Sensor	Break Lock Comm.	In	4	1
Radiation Sensor	Target Azimuth	In	4	6
Radiation Sensor	Target Elevation	In	4	6
Radiation Sensor	Operator Mode	Out	1	2
Radiation Sensor	Type Detected	Out	1	6
Radiation Sensor	Type Acquired	Out	1	6
Radiation Sensor	Target Azimuth	Out	4	6
Radiation Sensor	Target Elevation	Out	4	6
Radiation Sensor	Status	Out	1	<16
IR Line Scanner	Power On	In	1	1
IR Line Scanner	Mode	In	1	2
IR Line Scanner	V/H Ratio	In	4	7
IR Line Scanner	Contrast	In	1	2
IR Line Scanner	Roll Angle	In	8	7
IR Line Scanner	Drift Angle	In	4	6
IR Line Scanner	Lateral Angle	In	1	4
IR Line Scanner	Film/Tape Remaining	Out	1	8
IR Line Scanner	Status	Out	1	<16
Photo Camera	Power On	In	1	1
Photo Camera	Mode	In	1	1
Photo Camera	V/H	In	4	7
Photo Camera	Film Remaining	Out	1	8
Photo Camera	Roll Angle	In	8	7
Photo Camera	Drift Angle	In	4	6
Photo Camera	Lateral Angle	In	1	4
Photo Camera	Status	Out	1	<16
Weapon Station and Weapon	Power On	In	1	1
Weapon Station and Weapon	Mode	In	1	1
Weapon Station and Weapon	Master Arm	In	1	1
Weapon Station and Weapon	Weapon Arm	In	1	4

TABLE B-2. ARPV EQUIPMENT SIGNAL LIST (Continued)

Equipment	Signal	In/Out	Iteration Rate/Second	Number of Bits
Weapon Station and Weapon	Release Quantity	In	1	3
Weapon Station and Weapon	Release Interval	In	1	4
Weapon Station and Weapon	Release Enable	In	1	1
Weapon Station and Weapon	Release or Fire and Time	In	16	12
Weapon Station and Weapon	Retarded/Nonretarded	In	1	1
Weapon Station and Weapon	Select/Salvo Jettison, Weapons	In	4	4
Weapon Station and Weapon	Select/Salve Jettison, Racks	In	4	4
Weapon Station and Weapon	Ground Interlock	In	1	1
Weapon Station and Weapon	Store Type	Out	1	6
Weapon Station and Weapon	Weapon Ready	Out	1	1
Threat Warning	Radar Characteristics	Out	16	48
Threat Warning	Power On	In	1	1
Threat Warning	Band Select	In	1	3
Threat Warning	Threshold Adjust	In	4	6
Threat Warning	Threat Logic Select	In	4	4
Threat Warning	Mode	In	1	1
Threat Warning	Status	Out	1	<16
Active Jammer	Power On	In	1	1
Active Jammer	Mode	In	1	1
Active Jammer	Transmit On/Off	In	1	1
Active Jammer	Transmit Indication	Out	4	1
Active Jammer	Band Select	In	1	4
Active Jammer	Jam Mode Select	In	1	4
Active Jammer	Status	Out	1	<16
Miscellaneous	Oil Pressure		1	6
Miscellaneous	Oil Quantity		1	4
Miscellaneous	Fuel Quantity		1	8
Miscellaneous	Gear Up and Locked		1	2
Miscellaneous	Flap Position		1	4
Miscellaneous	Flap Control		1	4
Miscellaneous	Speed Brake Position		1	1
Miscellaneous	Speed Brake Control		1	1
Miscellaneous	Gear Down and Locked		1	2
Miscellaneous	Weight on Gear		1	1
Miscellaneous	Pilot Heat On/Off		1	1
Miscellaneous	Fuel Dump		1	1

APPENDIX C

ARPV ALGORITHMS AND PROCESSING REQUIREMENTS

APPENDIX C

ARPV ALGORITHMS AND PROCESSING REQUIREMENTS

From the assumed ARPV Mission Functions and Equipment (Appendix A and Appendix B) estimates can be made regarding algorithm and processing requirements. Since the ARPV is not totally defined, these estimates are of relative certainty rather than of absolute confidence.

In order to have a good representation of the total computational power onboard the aircraft, and for the purpose of projecting its application in the 1980 time frame, tasks of relatively high processing requirements were chosen. For the purposes of this study, processing requirements (memory and throughput) were found in existing documentation for a number of tasks. For other tasks, the processing requirements were estimated using engineering judgment. In general, the ARPV processing load was overestimated in order to simulate worst case conditions.

Each algorithm has the following requirements associated with it:

Instruction memory (permanent)–PROM

Data Memory (temporary)–RAM

Throughput depending on instructions executed and iteration rate.

Within the numbers describing the above-mentioned characteristics, 10 percent was added for the built-in test (BIT) requirement. Three categories of algorithms were considered:

Computational–In this category the main purpose of the algorithm is to provide numerical data needed by each function. Solution of equations or manipulation of data mathematically is included in this category

Logical–These algorithms are used mainly in decision making, table reading and packing or unpacking binary data. Required executive functions are also included in this category.

Subsystem Service (SSVC)–These are equipment-dependent algorithms and their only function is to control hardware operation and procedures (mode set, power on/off, input/output, scaling, etc.).

A list of algorithms under each category is given below:

Computational

- INS (Strapdown)
- Navigation Filter
- GPS
- Steering
- Flight Control
- Air Data
- Guidance
- MLS
- Line-Of-Sight Computation

- Target Position Computation
- Impact Point Computation
- TERCOM

Logical

- Mission Control
- Status Monitor
- Bus Control
- Active Jammer Control

SSVC

- Radar Altimeter
- Narrowband Data Link (NBDL)
- IFF
- Bulk Storage
- Aircraft Instrumentation
- FLIR
- Radiation Sensor
- Wideband Data Link (WBDL)
- Weapon Station
- IR Line Scanner
- Photo Camera
- Chaff Dispenser
- Threat Warning Receiver

Whenever a computational or logical algorithm interfaces directly with an external subsystem (sensor/actuator), an allowance was made to accommodate the SSVC requirement. These cases are:

INS

- IMU (inertial measurement unit)
- Remote compass

GPS

- GPS Receiving System

Flight Control

- Engine
- Actuators

Air Data

- Air Data Sensor

MLS

MLS Receiver System

TERCOM

TERCOM Sensor

Active Jammer Control

Active Jammer Transmitter

Table C-1 shows the ARPV processing requirements with the respective iteration rates.

Figure C-1 shows a block diagram for a representative strapdown inertial navigation system. The procedure used to obtain memory and throughput requirements for such an algorithm is illustrated in Figures C-2 through C-11. The number of add/subtract and multiply/divide operations is counted. For those operations the assumption is made that there is a need for three housekeeping instructions per arithmetic operation. In the course of the actual navigation computation, various trigonometric functions are required, e.g. sine, cosine, and tangent. One special-purpose subroutine is needed for matrix transpositions which involves the logical manipulation of indices. Some of the trigonometric subroutines and the matrix transposition are executed more than once, which contributes a factor of instruction iteration equal to the number of repetitions. The results of this general process are summarized in Tables C-2 and C-3.

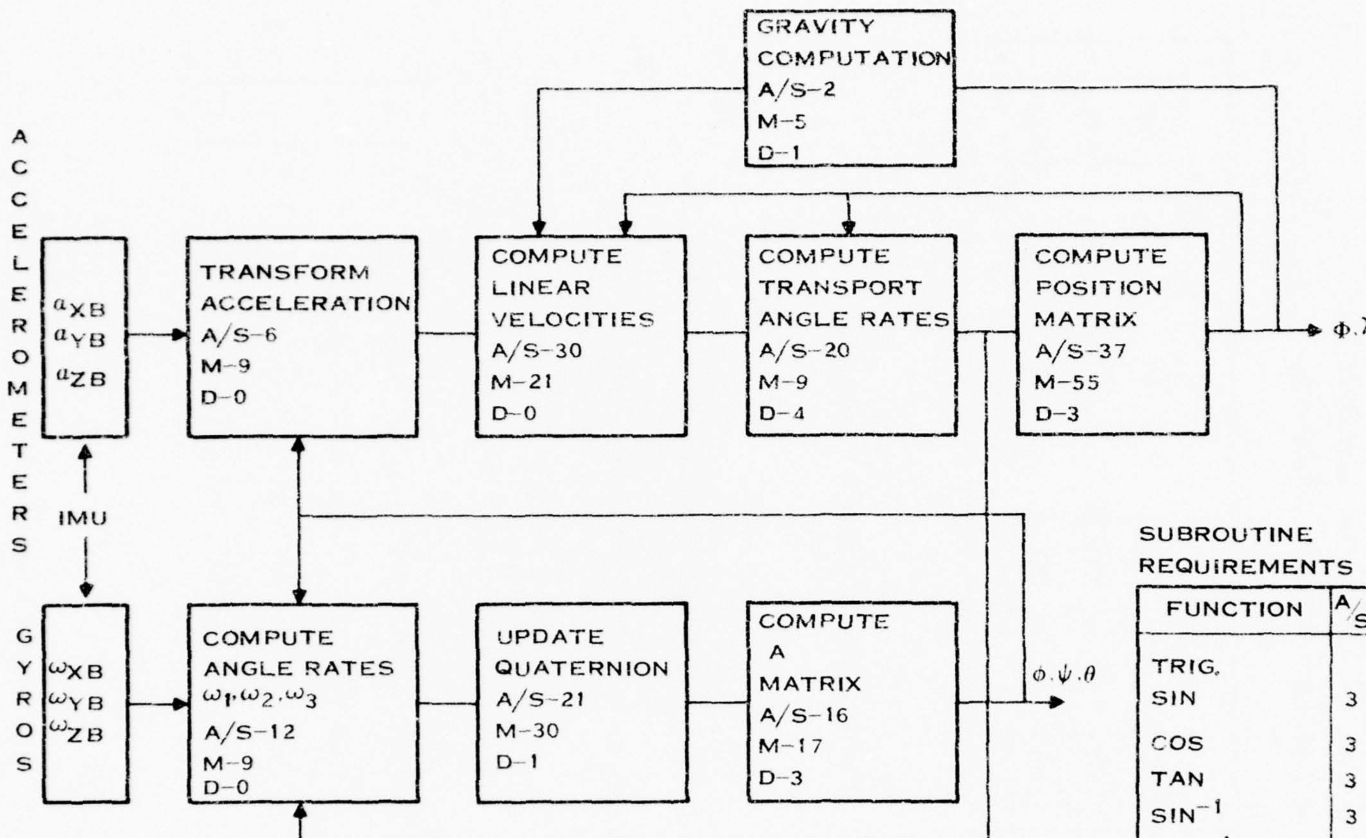
For IMU subsystem service, the memory estimate is 200 words for instructions and 50 words for data. The BIT estimate is 200 instructions (usually 10 percent of total tested algorithm instructions) and 50 data.

Following this independent study of the strapdown inertial navigation algorithm, a comparison was made between other existing studies (Table C-4). A final judgment was made, giving 3,500 words of memory and 65 KOPS throughput requirement.

TABLE C-1. ARPV PROCESSING REQUIREMENTS

Algorithm	Iteration Rate/Second	Instruction Memory 16-Bit Words	Data Memory 16-Bit Words	Total Memory	Throughput (KOPS)
Core					
INS (strapdown)	32	3,000	500	3,500	65
Navigation Filter	1/2	1,300	2,300	3,600	35
GPS	1/64	11,500	2,100	13,600	68
Steering	16	720	50	770	11.5
Flight Control	32	2,750	600	3,350	45
Air Data	4	560	75	635	6
Radar Altimeter SSVC*	32	150	30	180	0.5
Mission Control	16	3,300	2,000	5,300	15
Guidance	4	2,200	300	2,500	7
MLS	16	600	100	760	7.5
Status Monitor	1	550	500	1,050	3
Narrowband Data Link SSVC	32	550	500	1,050	3
IFF SSVC	4	150	20	170	0.5
Bus Control	32	1,000	2,000	3,000	30
Bulk Storage SSVC	16	50	20	70	0.5
Aircraft Instrumentation SSVC	1	70	30	100	0.5
Mission Specific					
Line-of-sight Computation	16	330	50	380	5
Target Position Computation	16	330	50	380	5
Impact Point Computation	16	1,760	200	1,960	71
FLIR SSVC	16	600	100	700	3
Radiation Sensor SSVC	4	600	100	700	2
TERCOM	32	2,450	2,000	4,450	70
Wideband Data Link SSVC	1	170	50	220	0.5
Weapon Station SSVC	16	550	100	650	3
IR Line Scanner SSVC	8	220	50	270	1
Photo Camera SSVC	8	220	50	270	1
Chaff Dispenser SSVC	1	330	60	390	1
Threat Warning RCVR SSVC	16	400	100	500	1.5
Active Jammer Control	16	880	200	1,080	7

*SSVC–Subsystem Service



SUBROUTINE REQUIREMENTS

FUNCTION	A/S	M	D	N*
TRIG.				
SIN	3	3	3	4
COS	3	3	3	4
TAN	3	3	3	4
SIN^{-1}	3	3	3	2
COS^{-1}	3	3	3	2
TAN^{-1}	3	3	3	2
TRANSPOSE	4	0	0	2

*N = NO. TIMES USED

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Figure C-1. Representative Strapdown Inertial Navigation System

$\omega_{XB}, \omega_{YB}, \omega_{ZB}$ = Gyro angular rate inputs along body axes

A = Direction cosine matrix relating body axes to stabilized frame

ρ_X, ρ_Y, ρ_Z = Transport angular rates with respect to earth of vehicle along stabilized axes

$\delta_{XB}, \delta_{YB}, \delta_{ZB}$ = Gyro drift compensation

$$\text{Gyros}\begin{bmatrix}\omega_{XB}\\ \omega_{YB}\\ \omega_{ZB}\end{bmatrix} \qquad \boxed{\begin{bmatrix}\omega_1\\ \omega_2\\ \omega_3\end{bmatrix} = \begin{bmatrix}\omega_{XB}\\ \omega_{YB}\\ \omega_{ZB}\end{bmatrix} - \begin{bmatrix}A\end{bmatrix}^{-1}\cdot\begin{bmatrix}\rho_X\\ \rho_Y\\ \rho_Z\end{bmatrix} - \begin{bmatrix}\delta_{XB}\\ \delta_{YB}\\ \delta_{ZB}\end{bmatrix}}$$

Figure C-2. Equation for Angle Rate Computation

$\omega_1, \omega_2, \omega_3$ = Angular rates of vehicle body frame relative to stabilized frame

q_1, q_2, q_3, q_4 = Quaternion elements which specify body frame relative to stabilized frame

$a = (\omega_1{}^2 + \omega_2{}^2 + \omega_3{}^2)\,\Delta t^2$

$$\begin{bmatrix}q_1\\ q_2\\ q_3\\ q_4\end{bmatrix}_{N+1} = \begin{bmatrix}q_1\\ q_2\\ q_3\\ q_4\end{bmatrix}_{N} + \tfrac{1}{2}\begin{bmatrix} a/4 & -\omega_1\,\Delta t & -\omega_2\,\Delta t & -\omega_3\,\Delta t\\ \omega_1\,\Delta t & a/4 & \omega_3\,\Delta t & -\omega_2\,\Delta t\\ \omega_2\,\Delta t & -\omega_3\,\Delta t & a/4 & \omega_1\,\Delta t\\ \omega_3\,\Delta t & \omega_2\,\Delta t & -\omega_1\,\Delta t & a/4 \end{bmatrix} \begin{bmatrix}q_1\\ q_2\\ q_3\\ q_4\end{bmatrix}_{N}$$

Figure C-3. Quaternion Update

a_{ij} = Elements of A matrix computed from quaternion elements

ψ, θ, ϕ = Conventional yaw, pitch roll of A/C body axes with respect to stabilized frame

$$\begin{bmatrix} A \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} = \begin{bmatrix} q_1^2 + q_2^2 - q_3^2 - q_4^2 & 2(q_2 q_3 - q_1 q_4) & 2(q_2 q_4 + q_1 q_3) \\ 2(q_2 q_3 + q_1 q_4) & q_1^2 - q_2^2 + q_3^2 + q_4^2 & 2(q_3 q_4 - q_1 q_2) \\ 2(q_2 q_4 - q_1 q_3) & 2(q_3 q_4 + q_1 q_2) & q_1^2 - q_2^2 - q_3^2 + q_4^2 \end{bmatrix}$$

$$\psi = \tan^{-1}\left(\frac{a_{12}}{a_{22}}\right)$$

$$\longrightarrow \theta = \sin^{-1}\left(a_{32}\right)$$

$$\phi = \tan^{-1}\left(\frac{a_{31}}{a_{33}}\right)$$

Figure C-4. "A" Matrix Computation

a_{xB}, a_{yB}, a_{zB} = Sensed accelerations

A_x, A_y, A_z = Sensed accelerations resolved along stabilized frame axes

$$\text{Accelerometers} \begin{bmatrix} a_{xB} \\ a_{yB} \\ a_{zB} \end{bmatrix} \longrightarrow \begin{bmatrix} A_X \\ A_Y \\ A_Z \end{bmatrix} = \begin{bmatrix} A \end{bmatrix} \begin{bmatrix} a_{xB} \\ a_{yB} \\ a_{zB} \end{bmatrix}$$

Figure C-5. Acceleration Transformation

$$h = \{K_1 (h_B - h) + V_z\} \Delta t$$

$$\begin{bmatrix} V_x \\ V_y \\ V_z \end{bmatrix} = \begin{bmatrix} \int A_x dt \\ \int A_y dt \\ \int A_z dt \end{bmatrix} + \int \left\{ \begin{bmatrix} 0 & (\rho_Z + 2\Omega_Z) & -(\rho_Y + 2\Omega_Y) \\ -(\rho_Z + 2\Omega_Z) & 0 & (\rho_X + 2\Omega_X) \\ (\rho_Y + 2\Omega_Y) & -(\rho_x + 2\Omega_x) & 0 \end{bmatrix} \cdot \begin{bmatrix} V_x \\ V_y \\ V_z \end{bmatrix} - \begin{bmatrix} g_x \\ g_y \\ g_z \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ K_2 (h_B - h) \end{bmatrix} \right\} dt$$

h = Smoothed vertical altitude of vehicle

h_B = Barometric altitude

V_x, V_y, V_z = Linear velocities of vehicle with respect to earth along stabilized frame axes

$\Omega_x, \Omega_y, \Omega_z$ = Earth-rate components along stabilized axes

g_x, g_y, g_x = Gravity components along stabilized axes

K_1, K_2 = Altitude feedback loop gains

Figure C-6. Linear Velocity Computation

R_p = Earth's polar radius

R_E = Earth's equatorial radius

f = 1/297 coefficient of flattening

$= 1 - R_p/R_E$

c_{ij} = Elements of direction cosine matrix specifying vehicular position relative to earth

$$\begin{bmatrix} P_x \\ P_y \\ P_z \end{bmatrix} \begin{matrix} = \\ = \\ = \end{matrix} \begin{bmatrix} -\frac{V_y}{R_E} \left\{1 - \frac{h}{R_E} - f(1 - 3C_{22}^2 - C_{21}^2)\right\} - \frac{V_x}{R_E}(2fC_{21}C_{22}) \\ \frac{V_x}{R_E} \left\{1 - \frac{h}{R_E} - f(1 - 3C_{21}^2 - C_{22}^2)\right\} + \frac{V_y}{R_E}(2fC_{21}C_{22}) \\ 0 \text{ or } \frac{C_{22}P_y + C_{21}P_x}{1 - C_{23}^2} C_{23} \end{bmatrix}$$

Figure C-7. Position Matrix Computation

Ω = Earth rate

$$\begin{bmatrix} \Omega_x \\ \Omega_y \\ \Omega_z \end{bmatrix} = \begin{bmatrix} C \end{bmatrix}^{-1} \cdot \begin{bmatrix} 0 \\ \Omega \\ 0 \end{bmatrix}$$

Figure C-8. Earth Rate Computation

Initial Position

$\Phi(0)$, $\lambda(0)$, $\alpha_T(0)$

$$\begin{aligned}
C_{11} &= \cos \alpha_T \cos \lambda - \sin \alpha_T \sin \Phi \sin \lambda \\
C_{12} &= -\sin \alpha_T \cos \lambda - \cos \alpha_T \sin \Phi \sin \lambda \\
C_{13} &= \cos \Phi \sin \lambda \\
C_{21} &= \sin \alpha_T \cos \Phi \\
C_{22} &= \cos \alpha_T \cos \Phi \\
C_{23} &= \sin \Phi \\
C_{31} &= -\cos \alpha_T \sin \lambda - \sin \alpha_T \sin \Phi \cos \lambda \\
C_{32} &= \sin \alpha_T \sin \lambda - \cos \alpha_T \sin \Phi \cos \lambda \\
C_{33} &= \cos \Phi \cos \lambda
\end{aligned}$$

$$\begin{bmatrix} C \end{bmatrix} = \int \left\{ \begin{bmatrix} C \end{bmatrix} \cdot \begin{bmatrix} 0 & -\rho_z & \rho_y \\ \rho_z & 0 & -\rho_x \\ -\rho_y & \rho_x & 0 \end{bmatrix} \right\} dt \longrightarrow$$

$$\Phi = \sin^{-1} C_{23}$$

$$\lambda = \tan^{-1} \frac{C_{13}}{C_{33}}$$

$$\alpha_T = \tan^{-1} \frac{C_{21}}{C_{22}}$$

Φ = Latitude
λ = Longitude
α_T = Wander angle with North of stabilized frame. (Zero for North-oriented system)

Figure C-9. Cosine Matrix Update

$$\begin{bmatrix} g_x \\ g_y \\ g_z \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ g_o \left(1 - 2\frac{h}{R_E} + \epsilon^2 C_{23}^2\right) \end{bmatrix}$$

g_o = Gravity constant = 9780.270 × 10^{-6} km/sec^2

ϵ = Eccentricity of a meridianal ellipse on the earth

Figure C-10. Gravity Computation

Compute Angle Rates $\omega_1, \omega_2, \omega_3$

$\omega_{XB}, \omega_{YB}, \omega_{ZB}$ = Gyro angular rate inputs along body axes.

A = Direction cosine matrix relating body axes to stabilized frame.

ρ_X, ρ_Y, ρ_Z = Transport angular rates of vehicle along stabilized axes, with respect to earth.

$\delta_{XB}, \delta_{YB}, \delta_{ZB}$ = Gyro drift compensation.

Gyros

$$\begin{bmatrix} \omega_{XB} \\ \omega_{YB} \\ \omega_{ZB} \end{bmatrix} \longrightarrow \boxed{\begin{bmatrix} \omega_1 \\ \omega_2 \\ \omega_3 \end{bmatrix} = \begin{bmatrix} \omega_{XB} \\ \omega_{YB} \\ \omega_{ZB} \end{bmatrix} - \begin{bmatrix} A \end{bmatrix}^{-1} \cdot \begin{bmatrix} \rho_X \\ \rho_Y \\ \rho_Z \end{bmatrix} - \begin{bmatrix} \delta_{XB} \\ \delta_{YB} \\ \delta_{ZB} \end{bmatrix}}$$

Total Operations

9 Multiplies

12 Add/Subtracts

$\begin{bmatrix} A \end{bmatrix}^{-1}$ = one matrix transposition

$\begin{bmatrix} B \end{bmatrix} = \begin{bmatrix} A \end{bmatrix}^{-1} \cdot \begin{bmatrix} \rho_X \\ \rho_Y \\ \rho_Z \end{bmatrix}$ 9 multiplies, 6 add/subtracts

$\begin{bmatrix} \omega_1 \\ \omega_2 \\ \omega_3 \end{bmatrix} = \begin{bmatrix} \omega_{XB} \\ \omega_{YB} \\ \omega_{ZB} \end{bmatrix} - \begin{bmatrix} B \end{bmatrix} - \begin{bmatrix} \delta_{XB} \\ \delta_{YB} \\ \delta_{ZB} \end{bmatrix}$ 6 add/subtracts

Figure C-11. Arithmetic Operations Required for Angle Rate Computation

TABLE C-2. INERTIAL NAVIGATION MEMORY REQUIREMENTS

Function	Memory Words Instructions	Data
Arithmetic and Housekeeping Operations	1787	250
IMU Subsystem Service	200	50
BIT	200	50
Total	2187	350

TABLE C-3. INERTIAL NAVIGATION PROCESSING REQUIREMENTS

Function	Instructions Mul./Div.	Add/Sub.	Other	Total Instruction Iterations Mul./Div.	Add/Sub.	Other
Inertial Navigation Computation	251	144	1185	251	144	1185
Trigonometric Subroutines	36	18	108	108	54	324
Matrix Transpose Subroutine	–		45	–	–	90
Total	287	162	1338	359	198	1599
	1787			Total Operations = 2156		

Average Throughput Requirement

= 2156 operations × 32 iterations/second

= 68.9 KOPS/second

Instruction Mix:

M/D – 17 percent

Other – 83 percent

TABLE C-4. INERTIAL NAVIGATION–COMPARISON WITH OTHER ESTIMATES

Source	Memory (Words)	Throughput (KOPS/Second)
TI-ARPV	2537	68.9
TI-DAIS	2417	45.6
Rockwell-ARPV	3000	40.0
Honeywell-DP/M	2550	33.3
Judgment	3500	65

APPENDIX D

SUMMARY OF SYSTEM NETWORK SIMULATOR (SNS) RESULTS

APPENDIX D

SUMMARY OF SYSTEM NETWORK SIMULATOR (SNS) RESULTS

I. DISCUSSION OF SNS RESULTS

This appendix contains a summary of simulation runs using the DP/M System Network Simulator (SNS). Three candidate avionic system configurations were simulated:

Centralized System

Hybrid System

DP/M System.

Note that the System Network Simulator used to simulate the ARPV configurations was a modified version of the SNS delivered to AFAL as part of Contract F33615-74-C-1018, Distributed Processor/Memory Architectures Design Program. The latter SNS was designed for the recommended PE architecture in the subject study and the executive and bus models were designed accordingly.

In the ARPV application, the MIL-STD-1553A protocol was used for the TDM bus. The earlier study used the round-robin method for the TDM bus. The bus model for the ARPV application had to be modified to simulate the MIL-STD-1553A protocol. Also, the executive models for the original SNS specifically modeled the executive for the earlier recommended architecture. In the ARPV application, these models should be looked upon as general-purpose with no meaningful input to the executive loading statistic for each PE in the simulation summary reports.

A brief description is provided of the changes that were made to existing SNS subroutines to simulate the ARPV avionic system configurations. Using the Hybrid system as an example, a listing of the user input data is provided in Table D-1. The meaning of each variable used in the user input data set is the same as defined in the description of the original SNS.

The only major change made to the SNS was to the bus transmit models: GBUSCX and LBUSCX. The round-robin passing of control mechanism in both models was removed. Message formats as dictated by MIL-STD-1553A are shown in Figure D-1. The statistics collection statements of the bus models were modified to correct for the resulting changes in time measurements.

The following conventions were established for user data:

Message types for terminal-to-terminal transfers shall be $100 \leq$ type <200

Message types for bus controller-to-terminal transfers shall be type <100.

A simplifying assumption was made for the Centralized configuration. Since all terminals except the computer are "dumb" terminals, there are no terminal-to-terminal transfers. The following variable was defined to differentiate between the centralized and the distributed configurations:

A named common "CONFIG" was defined with a logical variable ARCHIT as a member. CONFIG was defined in MAIN and in LBUSCX and GBUSCX. ARCHIT is set .FALSE. in MAIN when simulating centralized configurations and .TRUE. in MAIN for distributed type configurations. This variable impacts statistic collections in the various configurations.

TABLE D-1. HYBRID SIMULATION TEST CASE–
STRIKE CONFIGURATION

```
                      1111111111111111       1111111111111111       3333333333333333
&TTBD
WSIZE=20
GAPTME=5,
BITPRD=1,
MSYNC=0
&END
&TDEFN
TASKID = 1
&END
&MTBD
NUMMSG = 1
&END
&MDEFN
TYPE   = 21
LENGTH = 1
NUMDES = 1
TASKID = 41
CCLEN = 20
&END
&TDEFN
TASKID = 2
&END
&MTBD
NUMMSG = 1
&END
&MDEFN
TYPE   = 22
LENGTH = 1
NUMDES = 1
TASKID = 42
CCLEN = 20
&END
&TDEFN
TASKID = 3
&END
&MTBD
NUMMSG = 1
&END
&MDEFN
TYPE   = 23
LENGTH = 1
NUMDES = 1
TASKID = 43
CCLEN = 20
&END
&TDEFN
TASKID = 4
NPRED  = 1
&END
&MTBD
NUMMSG = 0
&END
&TDEFN
TASKID = 5
&END
```

TABLE D-1. HYBRID SIMULATION TEST CASE–
STRIKE CONFIGURATION (Continued)

```
&MTBD
NUMMSG = 1
&END
&MDEFN
TYPE   = 25
LENGTH = 1
NUMDES = 1
TASKID = 45
CCLEN = 20
&END
&TDEFN
TASKID = 6
&END
&MTBD
NUMMSG = 1
&END
&MDEFN
TYPE   = 26
LENGTH = 1
NUMDES = 1
TASKID = 46
CCLEN = 20
&END
&TDEFN
TASKID = 7
&END
&MTBD
NUMMSG = 1
&END
&MDEFN
TYPE   = 27
LENGTH = 1
NUMDES = 1
TASKID = 47
CCLEN = 20
&END
&TDEFN
TASKID = 8
&END
&MTBD
NUMMSG = 1
&END
&MDEFN
TYPE   = 28
LENGTH = 1
NUMDES = 1
TASKID = 48
CCLEN = 20
&END
&TDEFN
TASKID = 9
&END
&MTBD
NUMMSG = 1
&END
&MDEFN
TYPE   = 29
LENGTH = 1
```

TABLE D-1. HYBRID SIMULATION TEST CASE–
STRIKE CONFIGURATION (Continued)

```
NUMDES = 1
TASKID = 49
CCLEN = 20
&END
&TDEFN
TASKID = 10
&END
&MTBD
NUMMSG = 1
&END
&MDEFN
TYPE   = 30
LENGTH = 1
NUMDES = 1
TASKID = 50
CCLEN = 20
&END
&TDEFN
TASKID = 11
&END
&MTBD
NUMMSG = 1
&END
&MDEFN
TYPE   = 31
LENGTH = 1
NUMDES = 1
TASKID = 51
CCLEN = 20
&END
&TDEFN
TASKID = 12
&END
&MTBD
NUMMSG = 1
&END
&MDEFN
TYPE   = 32
LENGTH = 1
NUMDES = 1
TASKID = 52
CCLEN = 20
&END
&TDEFN
TASKID = 13
&END
&MTBD
NUMMSG = 1
&END
&MDEFN
TYPE   = 33
LENGTH = 1
NUMDES = 1
TASKID = 53
CCLEN = 20
&END
&TDEFN
TASKID = 14
```

TABLE D-1. HYBRID SIMULATION TEST CASE–
STRIKE CONFIGURATION (Continued)

```
&END
&MTBD
NUMMSG = 1
&END
&MDEFN
TYPE   = 34
LENGTH = 1
NUMDES = 1
TASKID = 54
CCLEN = 20
&END
&TDEFN
TASKID = 15
&END
&MTBD
NUMMSG = 1
&END
&MDEFN
TYPE   = 35
LENGTH = 1
NUMDES = 1
TASKID = 55
CCLEN = 20
&END
&TDEFN
TASKID = 16
&END
&MTBD
NUMMSG = 1
&END
&MDEFN
TYPE   = 36
LENGTH = 1
NUMDES = 1
TASKID = 56
CCLEN = 20
&END
&TDEFN
TASKID = 17
&END
&MTBD
NUMMSG = 1
&END
&MDEFN
TYPE   = 37
LENGTH = 1
NUMDES = 1
TASKID = 57
CCLEN = 20
&END
&TDEFN
TASKID = 41
TNAME  = 40H RADAR ALTIMETER
RTYPE  = 180
XTIME  = 157
NPRED  = 1
NIMSG  = 1
IMTYPE = 21
```

TABLE D-1. HYBRID SIMULATION TEST CASE–
STRIKE CONFIGURATION (*Continued*)

```
NUMSUC = 1
SRID   = 53
&END
&MTBD
NUMMSG = 2
&END
&MDEFN
TYPE   = 112
LENGTH = 1
NUMDES = 1
TASKID = 48
CCLEN = 20
&END
&MDEFN
TYPE   = 1
LENGTH = 1
NUMDES = 1
TASKID = 4
CCLEN = 20
&END
&TDEFN
TASKID = 42
TNAME  = 40H INS
RTYPE  = 3500
XTIME  = 20313
NPRED  = 1
NIMSG  = 1
IMTYPE = 22
&END
&MTBD
NUMMSG = 5
&END
&MDEFN
TYPE   = 100
LENGTH = 18
NUMDES = 1
TASKID = 50
CCLEN = 20
&END
&MDEFN
TYPE   = 101
LENGTH = 18
NUMDES = 1
TASKID = 53
CCLEN = 20
&END
&MDEFN
TYPE   = 102
LENGTH = 18
NUMDES = 1
TASKID = 49
CCLEN = 20
&END
&MDEFN
TYPE   = 103
LENGTH = 12
NUMDES = 1
TASKID = 51
```

TABLE D-1. HYBRID SIMULATION TEST CASE– STRIKE CONFIGURATION (Continued)

```
CCLEN = 20
&END
&MDEFN
TYPE    = 2
LENGTH = 1
NUMDES = 1
TASKID = 4
CCLEN = 20
&END
&TDEFN
TASKID = 43
TNAME  = 40H RADIATION SENSOR
RTYPE  = 700
XTIME  = 625
NPRED  = 1
NIMSG  = 1
IMTYPE = 23
&END
&MTBD
NUMMSG = 2
&END
&MDEFN
TYPE    = 310
LENGTH = 2
NUMDES = 1
TASKID = 54
CCLEN = 20
&END
&MDEFN
TYPE    = 3
LENGTH = 1
NUMDES = 1
TASKID = 4
CCLEN = 20
&END
&TDEFN
TASKID = 45
TNAME  = 40H AIR DATA
RTYPE  = 635
XTIME  = 1875
NPRED  = 1
NIMSG  = 1
IMTYPE = 25
NUMSUC = 1
SRID   = 53
&END
&MTBD
NUMMSG = 2
&END
&MDEFN
TYPE    = 307
LENGTH = 3
NUMDES = 1
TASKID = 49
CCLEN = 20
&END
&MDEFN
TYPE    = 5
```

TABLE D-1. HYBRID SIMULATION TEST CASE–
STRIKE CONFIGURATION (Continued)

```
LENGTH = 1
NUMDES = 1
TASKID = 4
CCLEN = 20
&END
&TDEFN
TASKID = 46
TNAME  = 40H STATUS MONITOR
RTYPE  = 1050
XTIME  = 938
NPRED  = 1
NIMSG  = 1
IMTYPE = 26
&END
&MTBD
NUMMSG = 2
&END
&MDEFN
TYPE   = 113
LENGTH = 25
NUMDES = 1
TASKID = 47
CCLEN = 20
&END
&MDEFN
TYPE   = 6
LENGTH = 1
NUMDES = 1
TASKID = 4
CCLEN = 20
&END
&TDEFN
TASKID = 47
TNAME  = 40H NARROW BAND DATA LINK
RTYPE  = 1050
XTIME  = 938
NPRED  = 2
NIMSG  = 2
IMTYPE = 27,113
&END
&MTBD
NUMMSG = 1
&END
&MDEFN
TYPE   = 7
LENGTH = 1
NUMDES = 1
TASKID = 4
CCLEN = 20
&END
&TDEFN
TASKID = 48
TNAME  = 40H TARGET POS. COMP.
RTYPE  = 380
XTIME  = 1563
NPRED  = 2
NIMSG  = 2
IMTYPE = 28,112
```

**TABLE D-1. HYBRID SIMULATION TEST CASE–
STRIKE CONFIGURATION (Continued)**

```
NUMSUC = 1
SRID   = 49
&END
&MTBD
NUMMSG = 1
&END
&MDEFN
TYPE   = 8
LENGTH = 1
NUMDES = 1
TASKID = 4
CCLEN = 20
&END
&TDEFN
TASKID = 49
TNAME  = 40H IMPACT COMP.
RTYPE  = 1960
XTIME  = 22188
NPRED  = 3
NIMSG  = 2
IMTYPE = 29,102
&END
&MTBD
NUMMSG = 2
&END
&MDEFN
TYPE   = 114
LENGTH = 1
NUMDES = 1
TASKID = 54
CCLEN = 20
&END
&MDEFN
TYPE   = 9
LENGTH = 1
NUMDES = 1
TASKID = 4
CCLEN = 20
&END
&TDEFN
TASKID = 50
TNAME  = 40H NAV. FILTER
RTYPE  = 3600
XTIME  = 0
NPRED  = 2
NIMSG  = 2
IMTYPE = 30,100
&END
&MTBD
NUMMSG = 1
&END
&MDEFN
TYPE   = 10
LENGTH = 1
NUMDES = 1
TASKID = 4
CCLEN = 20
&END
```

TABLE D-1. HYBRID SIMULATION TEST CASE–
STRIKE CONFIGURATION (Continued)

```
&TDEFN
TASKID = 51
TNAME  = 40H FLIGHT CONTROL
RTYPE  = 3350
XTIME  = 14063
NPRED  = 2
NIMSG  = 2
IMTYPE = 31,103
&END
&MTBD
NUMMSG = 1
&END
&MDEFN
TYPE   = 11
LENGTH = 1
NUMDES = 1
TASKID = 4
CCLEN = 20
&END
&TDEFN
TASKID = 52
TNAME  = 40H STEERING
RTYPE  = 770
XTIME  = 3594
NPRED  = 1
NIMSG  = 1
IMTYPE = 32
&END
&MTBD
NUMMSG = 2
&END
&MDEFN
TYPE   = 308
LENGTH = 5
NUMDES = 1
TASKID = 51
CCLEN = 20
&END
&MDEFN
TYPE   = 12
LENGTH = 1
NUMDES = 1
TASKID = 4
CCLEN = 20
&END
&TDEFN
TASKID = 53
TNAME  = 40H GUIDANCE
RTYPE  = 2500
XTIME  = 2188
NPRED  = 4
NIMSG  = 2
IMTYPE = 33,101
&END
&MTBD
NUMMSG = 1
&END
&MDEFN
```

TABLE D-1. HYBRID SIMULATION TEST CASE–
STRIKE CONFIGURATION (Continued)

```
TYPE   = 13
LENGTH = 1
NUMDES = 1
TASKID = 4
CCLEN = 20
&END
&TDEFN
TASKID = 54
TNAME  = 40H MISSION CONTROL
RTYPE  = 5300
XTIME  = 4688
NPRED  = 2
NIMSG  = 2
IMTYPE = 34,144
&END
&MTBD
NUMMSG = 4
&END
&MDEFN
TYPE   = 111
LENGTH = 2
NUMDES = 1
TASKID = 56
CCLEN = 20
&END
&MDEFN
TYPE   = 115
LENGTH = 2
NUMDES = 1
TASKID = 57
CCLEN = 20
&END
&MDEFN
TYPE   = 316
LENGTH = 2
NUMDES = 1
TASKID = 55
CCLEN = 20
&END
&MDEFN
TYPE   = 14
LENGTH = 1
NUMDES = 1
TASKID = 4
CCLEN = 20
&END
&TDEFN
TASKID = 55
TNAME  = 40H WIDE BAND DATA LINK
RTYPE  = 220
XTIME  = 157
NPRED  = 1
NIMSG  = 1
IMTYPE = 35
&END
&MTBD
NUMMSG = 1
&END
```

TABLE D-1. HYBRID SIMULATION TEST CASE—
STRIKE CONFIGURATION (Continued)

```
&MDEFN
TYPE    = 15
LENGTH = 1
NUMDES = 1
TASKID = 4
CCLEN = 20
&END
&TDEFN
TASKID = 56
TNAME  = 40H FLIR
RTYPE  = 700
XTIME  = 938
NPRED  = 2
NIMSG  = 2
IMTYPE = 36,111
&END
&MTBD
NUMMSG = 1
&END
&MDEFN
TYPE    = 16
LENGTH = 1
NUMDES = 1
TASKID = 4
CCLEN = 20
&END
&TDEFN
LAST = .TRUE.
TASKID = 57
TNAME  = 40H WEAPON STATION
RTYPE  = 650
XTIME  = 938
NPRED  = 2
NIMSG  = 2
IMTYPE = 37,115
&END
&MTBD
NUMMSG = 1
&END
&MDEFN
TYPE    = 17
LENGTH = 1
NUMDES = 1
TASKID = 4
CCLEN = 20
&END
&GBDEF
TOTPE  = 9
GBCL   = 1,2,3,4,5,6,7,8,9
BLGTH  = 9
&END
&LBDEF
NUMPE  = 1
PECON  = 1
BLGTH  = 1
&END
&LBDEF
NUMPE  = 1
```

TABLE D-1. HYBRID SIMULATION TEST CASE–
STRIKE CONFIGURATION (Continued)

```
PECON  = 2
BLGTH  = 1
&END
&LBDEF
NUMPE  = 1
PECON  = 3
BLGTH  = 1
&END
&LBDEF
NUMPE  = 1
PECON  = 4
BLGTH  = 1
&END
&LBDEF
NUMPE  = 1
PECON  = 5
BLGTH  = 1
&END
&LBDEF
NUMPE  = 1
PECON  = 6
BLGTH  = 1
&END
&LBDEF
NUMPE  = 1
PECON  = 7
BLGTH  = 1
&END
&LBDEF
NUMPE  = 1
PECON  = 8
BLGTH  = 1
&END
&LBDEF
LAST=     .TRUE.
NUMPE  = 1
PECON  = 9
BLGTH  = 1
&END
&DEFINE
PEID   = 1
NUMTSK = 17
TASKS  = 1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17
&END
&DEFINE
PEID   = 2
NUMTSK = 1
TASKS  = 42
&END
&DEFINE
PEID   = 3
NUMTSK = 6
TASKS  = 41,45,46,52,53,54
&END
&DEFINE
PEID   = 4
NUMTSK = 2
TASKS  = 47,50
```

TABLE D-1. HYBRID SIMULATION TEST CASE–
STRIKE CONFIGURATION (Continued)

```
&END
&DEFINE
PEID   = 5
NUMTSK = 1
TASKS  = 51
&END
&DEFINE
PEID   = 6
NUMTSK = 3
TASKS  = 43,48,49
&END
&DEFINE
PEID   = 7
NUMTSK = 1
TASKS  = 57
&END
&DEFINE
PEID   = 8
NUMTSK = 1
TASKS  = 56
&END
&DEFINE
PEID   = 9
NUMTSK = 1
TASKS  = 55
LAST=     .TRUE.
&END
&FNDEFN
ID     = 1
RUNT   = 1000
ITER   = 31250
NUMPE  = 1
SFPE   = 3
&END
&FNDEFN
ID     = 2
RUNT   = 2000
ITER   = 31250
NUMPE  = 1
SFPE   = 3
&END
&FNDEFN
ID     = 3
RUNT   = 3000
ITER   = 250000
NUMPE  = 1
SFPE   = 6
&END
&FNDEFN
ID     = 5
RUNT   = 4000
ITER   = 250000
NUMPE  = 1
SFPE   = 3
&END
&FNDEFN
ID     = 6
RUNT   = 5000
```

TABLE D-1. HYBRID SIMULATION TEST CASE–
STRIKE CONFIGURATION (Continued)

```
ITER    = 1000000
NUMPE   = 1
SFPE    = 3
&END
&FNDEFN
ID      = 7
RUNT    = 6000
ITER    = 62500
NUMPE   = 1
SFPE    = 4
&END
&FNDEFN
ID      = 8
RUNT    = 7000
ITER    = 62500
NUMPE   = 1
SFPE    = 6
&END
&FNDEFN
ID      = 9
RUNT    = 21350
ITER    = 62500
NUMPE   = 1
SFPE    = 6
&END
&FNDEFN
ID      = 10
RUNT    = 22350
ITER    = 2000000
NUMPE   = 1
SFPE    = 4
&END
&FNDEFN
ID      = 11
RUNT    = 23350
ITER    = 31250
NUMPE   = 1
SFPE    = 5
&END
&FNDEFN
ID      = 12
RUNT    = 26150
ITER    = 62500
NUMPE   = 1
SFPE    = 3
&END
&FNDEFN
ID      = 13
RUNT    = 28790
ITER    = 250000
NUMPE   = 1
SFPE    = 3
&END
&FNDEFN
ID      = 14
RUNT    = 42600
ITER    = 62500
NUMPE   = 1
```

TABLE D-1. HYBRID SIMULATION TEST CASE–
STRIKE CONFIGURATION (Continued)

```
SFPE    = 3
&END
&FNDEFN
ID      = 15
RUNT    = 47350
ITER    = 1000000
NUMPE   = 1
SFPE    = 9
&END
&FNDEFN
ID      = 16
RUNT    = 48400
ITER    =  62500
NUMPE   = 1
SFPE    = 8
&END
&FNDEFN
ID      = 17
RUNT    = 49400
ITER    = 62500
NUMPE   = 1
SFPE    = 7
LAST=     .TRUE.
&END
```

TABLE D-2. ALGORITHM SIGNAL LIST

Algorithm	No. of Msg. In	Origin	No. of Msg. Out	Destination	Msg. Size ×16 BITS	Iteration/ Second
Mission Control	2	Weap. Stat.			1	1
			2	Weap. Stat.	1	4
			1	Weap. Stat.	1	16
			8	Weap. Stat.	1	1
			3	IFF	1	1
			3	IFF	1	4
			4	MLS	1	1
			3	NBDL	1	1
			2	NBDL	1	16
	NxIn	NBDL			1	16
			6	WBDL	1	1
			1	Rem. Comps.	1	1
			1	IMU	1	1
			2	INS	1	1
			1	GPS	1	1
			2	Rad. Altm.	1	1
			1	Air Data	1	1
			1	TERCOM	1	1
			1	TERCOM	1	4
			2	TERCOM	1	8
			1	Flt. Cont.	1	1
			1	Flt. Cont.	1	1
			2	FLIR	1	1
			6	FLIR	1	4
			2	Rad. Sen.	1	1
			1	Rad. Sen.	1	4
			2	Gnd Trk. Guidance	2	1
			1	Ter. Following	1	1
			3	Climb/Desc. Guidance	1	4
			1	INS	1	4
			3	INS	2	32
INS	2	Mis. Con.			1	1
	2	Rem. Comps.			1	16
	1	Mis. Con.			1	4
	1	IMU			1	32
	3	IMU			1	32
	3	Mis. Con.			2	32
			9	Guidance	2	32
			9	Nav. Filt.	2	32
			9	Impct. Pnt.	2	32
			3	LOS	2	32

TABLE D-2. ALGORITHM SIGNAL LIST (Continued)

Algorithm	No. of Msg. In	Origin	No. of Msg. Out	Destination	Msg. Size X16 BITS	Iteration/ Second
Navigation Filter	9	INS			2	32
			9	INS	2	1/2
Guidance						
(a) Ground Tracking Mode	2	INS			2	4
	4	Mis. Con.			2	4
	1	INS			1	1
			1	Steering	1	1
(b) Terrain Following Mode	1	Rad. Altm.			1	32
	2	INS			1	32
	1	Mis. Con.			1	32
			1	Steering	1	4
(c) Climb/Descend and Cruise Vertical Mode	2	Air Data			1	1
	2	INS			1	1
	3	Mis. Con.			1	1
			1	Steering	1	1
(d) Weapon Delivery Vertical Mode	4	INS			1	16
	3	Impct. Pnt.			1	16
			1	Steering	1	4
(e) Weapon Delivery Horizontal Mode	1	INS			1	16
	2	Impct. Pnt.			1	16
			1	Steering	1	4
(f) MLS Guidance Mode	3	MLS			1	16
	1	INS			1	16
			2	Steering	1	4
Air Data	1	Mis. Con.			1	1
			1	Stat. Mon.	1	1
			3	Guidance	1	4
			3	Flt. Cont.	1	4
	3	Air. Dt. Sen.			1	4
GPS	8	GPS Rcvr.			2	32
			6	Nav. Filt.	2	1/64
	1	Mis. Con.			1	1
			1	Stat. Mon.	1	1
IFF SSVC	1	Mis. Con.			1	1
			1	Stat. Mon.	1	1
Radar Altimeter SSVC	2	Mis. Con.			1	1
			1	Stat. Mon.	1	1
			1	Guidance	1	32
			1	Tgt. Pos.	1	32

TABLE D-2. ALGORITHM SIGNAL LIST (Continued)

Algorithm	No. of Msg. In	Origin	No. of Msg. Out	Destination	Msg. Size ×16 BITS	Iteration/ Second
TERCOM	1	Mis. Con.			1	1
			1	Stat. Mon.	1	1
	2	Mis. Con.			1	8
			3	Nav. Filt.	1	4
MLS	4	Mis. Con.			1	1
			1	Stat. Mon.	1	1
			3	Guidance	1	16
Target Line-of-Sight Computation	1	Mis. Con.			1	1
	3	Mis. Con.			2	32
	3	INS			2	32
			2	Rad. Sens.	2	32
Radiation Sensor SSVC	1	Mis. Con.			1	1
			1	Stat. Mon.	1	1
	2	LOS Comp.			2	32
			2	Tgt. Pos. Com.	2	32
Target Position Computation	1	Mis. Con.			1	1
	2	Rad. Sens.			2	32
			3	Impct. Pnt.	2	32
Impact Point Computation	1	Mis. Con.			1	1
	3	Tgt. Pos. Com.			2	32
	9	INS			2	32
	2	Air Data			1	4
			3	Guidance	2	32
Flight Control (and Engine Control)	6	INS			2	32
	3	Steering			2	16
	3	Air Data			1	4
	2	Mis. Con.			1	1
			2	Stat. Mon.	1	1
	1	Steering			2	16
Steering	3	Guidance			2	4
			4	Flt. Cont.	2	16
Wideband Data Link SSVC	6	Mis. Con.			1	1
			1	Stat. Mon.	1	1
Narrowband Data Link SSVC	3	Mis. Con.			1	1
	1				1	16
			1	Stat. Mon.	1	1
	N	(Any)			1	16
			M	(Any)	1	16

TABLE D-2. ALGORITHM SIGNAL LIST (Continued)

Algorithm	No. of Msg. In	Origin	No. of Msg. Out	Destination	Msg. Size ×16 BITS	Iteration/ Second
FLIR	2	Mis. Con.			1	1
	2	LOS Comp.			2	32
	6	Mis. Con.			1	4
			5	Stat. Mon.	1	1
			2	Mis. Con.	1	4
Status Monitor	K	K Subsyst			1	1
			L	NBDL	1	16
			1	Mis. Con.	1	1
Weapon Station SSVC	8	Mis. Con.			1	1
	1	Mis. Con.			1	16
	2	Mis. Con.			1	4
			2	Stat. Mon.	1	1
Chaff Dispenser SSVC	4	Mis. Con.			1	1
			2	Stat. Mon.	1	1
Threat Warning RCVR. SSVC	3	Mis. Con.			1	1
	2	Mis. Con.			1	4
			1	Act. Jam.	3	16
			1	Stat. Mon.	1	1
Active Jammer Control	3	Mis. Con.			1	1
			1	Mis. Con.	1	4
			1	Stat. Mon.	1	1
IR Line Scanner SSVC	3	Mis Con.			1	1
	1	Guidance			1	4
	3	INS			2	32
			2	Stat. Mon.	1	1
Photo Camera SSVC	3	Mis. Con.			1	1
	1	Guidance			1	4
	3	INS	2	Stat. Mon.	2	32

If a task executes, but the next scheduled time to begin goes beyond the simulated time, the message ID should be >300 unless a predecessor-successor relationship exists with another task. The messages in Table D-2 also account for cases where identical pieces of information have different destinations. Certain messages denoted as NxIN or KxIN are determined by the nature of equipment such as Narrowband Data Link when the exact number of words is not known at this point. The upper boundary in this case is 32 words long per MIL-STD-1553A.

Table D-3 contains the different modes of the Guidance algorithm, the input signals required (IN) and signals generated (OUT). Table D-2 shows the Guidance signal flow (incoming and outgoing) in further detail, separated into its different modes.

Figure D-2 shows the summary of the bus traffic results for all three configurations, during the weapon delivery segment of the strike mission. The bus traffic summary shows total bus traffic in KBPS and also divided into percentages utilized for data, overhead, and gap. The sync percentage is shown as zero due to the assumption of 20 bits per word to include the required sync.

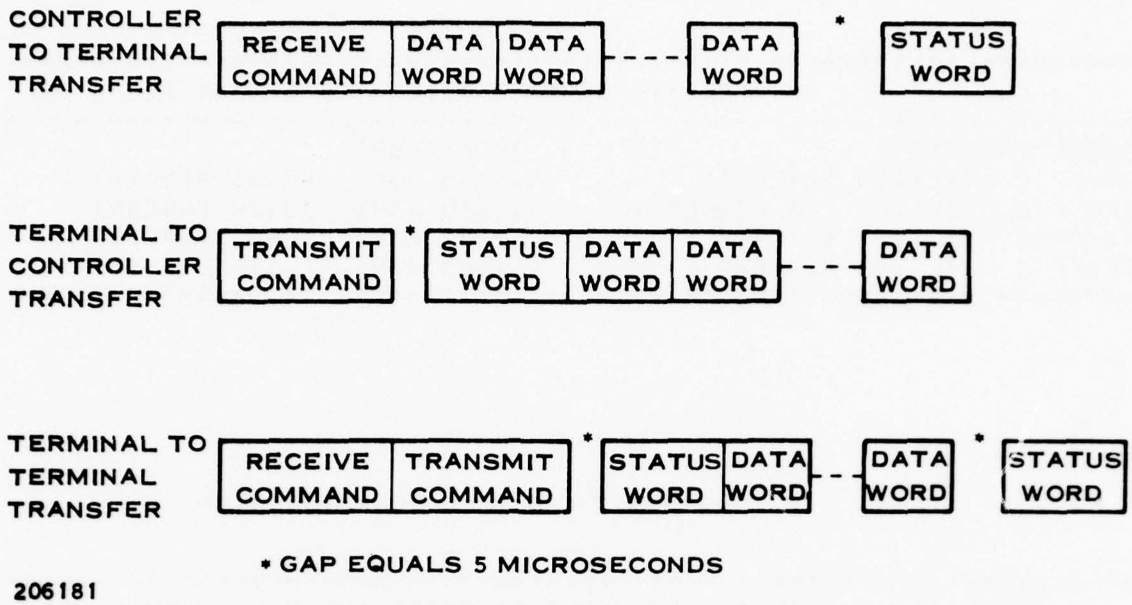

Figure D-1. Message Formats for MIL-STD-1553A Data Bus

For the Centralized configuration a user-defined "trick" was utilized to simulate this case within the constraints of the SNS executive models. The central computer was defined as PE 10 and assigned all the processing load. The bus controller (which would normally be resident inside the computer) was defined as PE 1 and connected to PE 10 by a local bus.

Other operations of the ARPV simulator are the same as in the original SNS.

The lengths of the messages are determined by the number of generated output words from a particular algorithm. For example, the Air Data algorithm generates three pieces of information: true airspeed, angle of attack, and altitude. Therefore, the message length is three, assuming single-word precision. If double precision were assumed, the message length would be six.

If this message has multiple destinations, the output queue should have as many messages as there are receivers, with different IDs (over 100 if the message is required and over 300 if the update is not necessary). If only one of the generated data words is required by one of the receivers, the message length should be adjusted accordingly. If the receiving task is collocated in the same processing element with the transmitting task, the message is not accounted for, since there is no bus transfer.

Table D-2 summarizes the number of messages flowing between the assumed algorithms as well as their size (precision required in terms of 16-bit words) and iteration rate of message generation.

CENTRALIZED SYSTEM–STRIKE CONFIGURATION

```
*****************************************************************
                  BUS TRAFFIC DECOMPOSITION FOR GLOBAL BUS    99
-----------------------------------------------------------------
TOTAL TRAFFIC                    =      39.65 KBPS
TRAFFIC UTILIZED FOR DATA        =      24.80 KBPS   62.55 PERCENT
TRAFFIC UTILIZED FOR HEADER      =      13.20 KBPS   33.29 PERCENT
TRAFFIC UTILIZED FOR SYNC        =       0.0  KBPS    0.0  PERCENT
TRAFFIC UTILIZED FOR GAP         =       1.65 KBPS    4.16 PERCENT
*****************************************************************
```

HYBRID SYSTEM–STRIKE CONFIGURATION

```
*****************************************************************
                  BUS TRAFFIC DECOMPOSITION FOR GLOBAL BUS    99
-----------------------------------------------------------------
TOTAL TRAFFIC                    =      93.90 KBPS
TRAFFIC UTILIZED FOR DATA        =      49.80 KBPS   53.04 PERCENT
TRAFFIC UTILIZED FOR HEADER      =      39.20 KBPS   41.75 PERCENT
TRAFFIC UTILIZED FOR SYNC        =       0.0  KBPS    0.0  PERCENT
TRAFFIC UTILIZED FOR GAP         =       4.90 KBPS    5.22 PERCENT
*****************************************************************
```

DP/M SYSTEM–STRIKE CONFIURATION

```
*****************************************************************
                  BUS TRAFFIC DECOMPOSITION FOR GLOBAL BUS    99
-----------------------------------------------------------------
TOTAL TRAFFIC                    =     101.25 KBPS
TRAFFIC UTILIZED FOR DATA        =      52.20 KBPS   51.56 PERCENT
TRAFFIC UTILIZED FOR HEADER      =      43.60 KBPS   43.06 PERCENT
TRAFFIC UTILIZED FOR SYNC        =       0.0  KBPS    0.0  PERCENT
TRAFFIC UTILIZED FOR GAP         =       5.45 KBPS    5.38 PERCENT
*****************************************************************
```

Figure D-2. SNS Result Summary

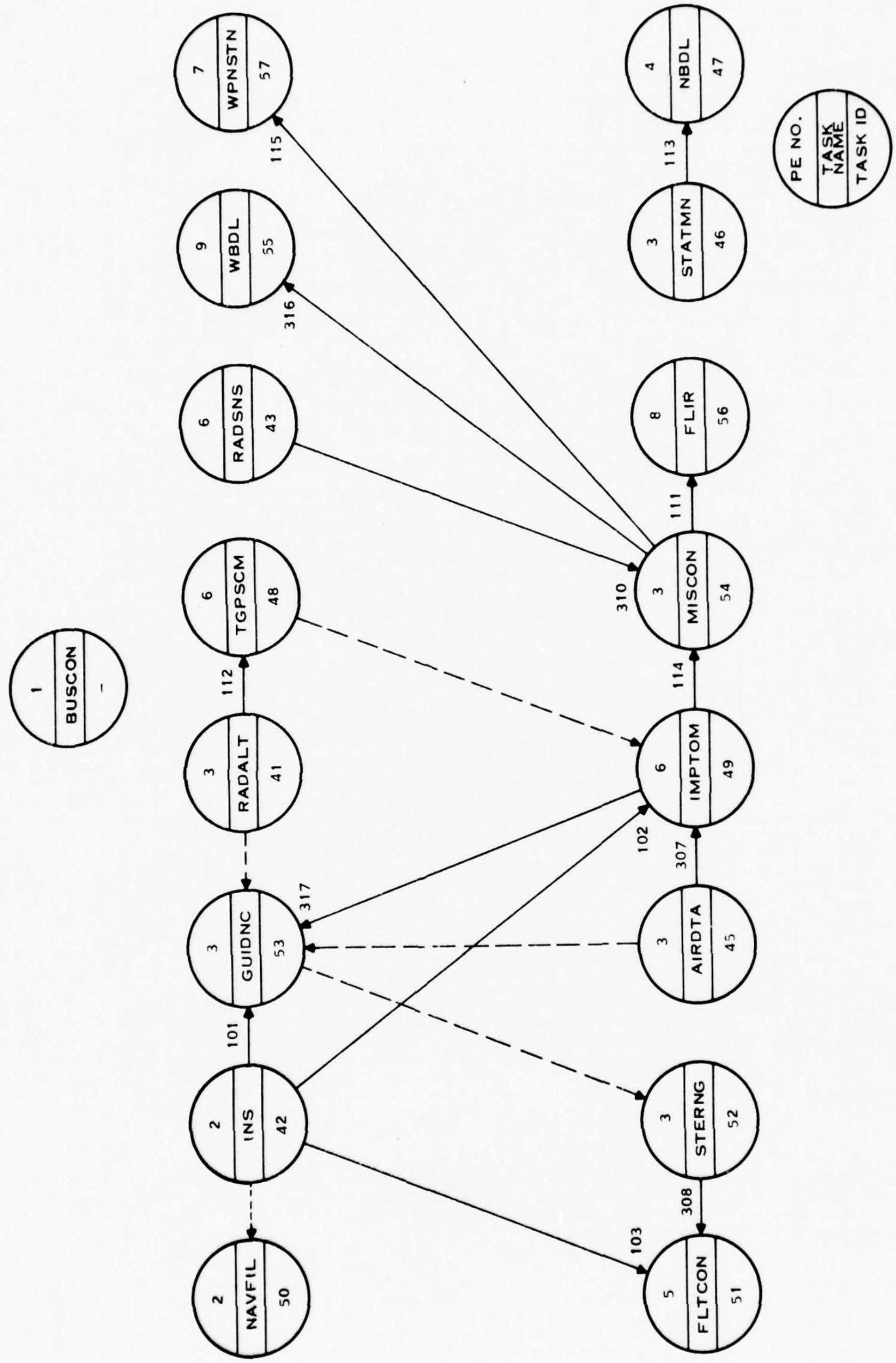

Figure D-3. Interfunctional Relationships

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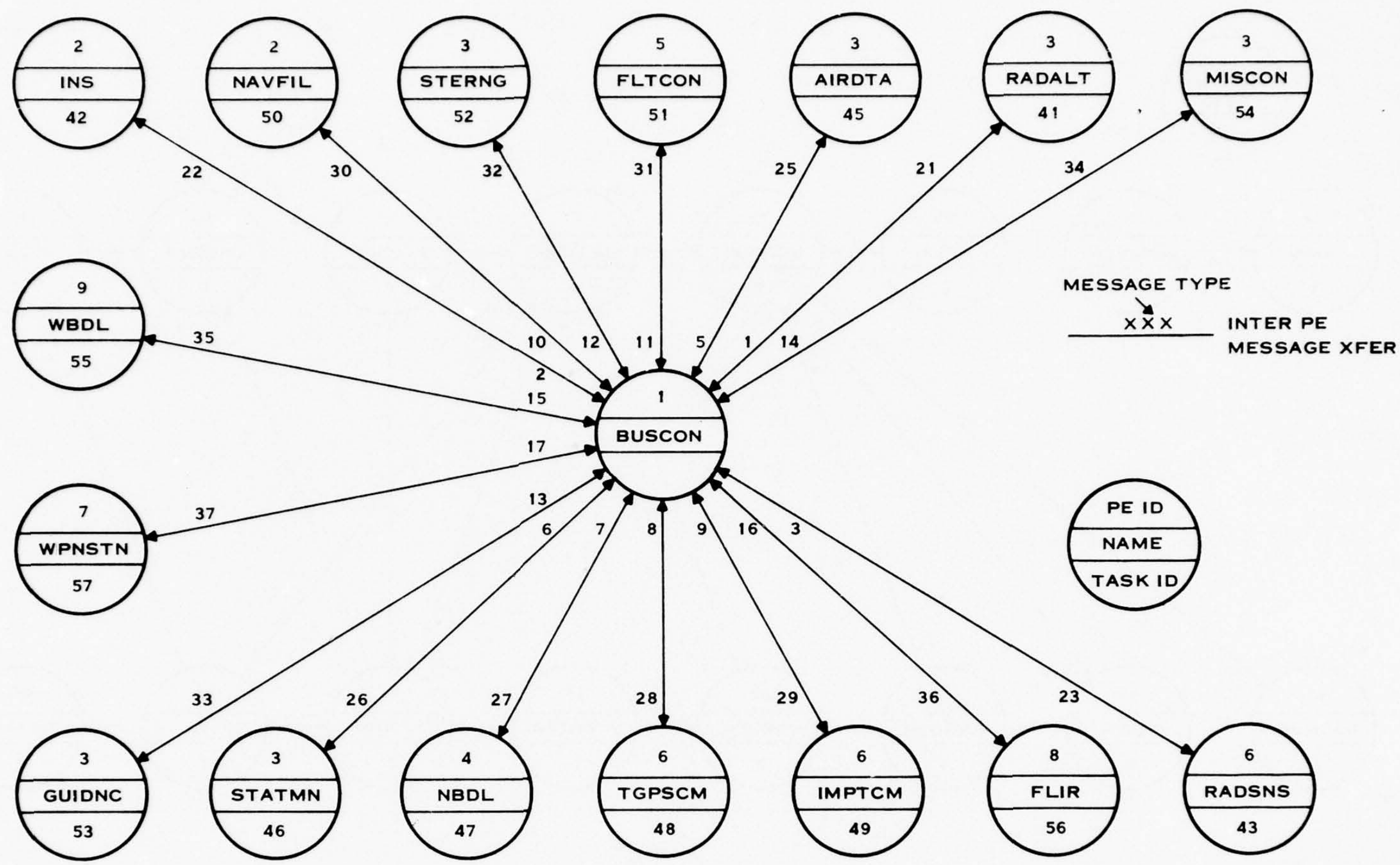

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Figure D-4. Bus Controller to Task Messages

TABLE D-3. SIGNAL LIST FOR GUIDANCE ALGORITHM

Routine	Signal	In/Out
	ACTUAL PRESENT POSITION X	IN
	ACTUAL PRESENT POSITION Y	IN
	PROGRAMMED PRESENT POSITION X	IN
	PROGRAMMED PRESENT POSITION Y	IN
Ground Track Guidance	NEXT CHECKPOINT POSITION X	IN
	NEXT CHECKPOINT POSITION Y	IN
	PRESENT HEADING	IN
	CORRECT HEADING	OUT
	RADAR ALTITUDE	IN
	PITCH ATTITUDE	IN
Terrain Following Guidance	VERTICAL VELOCITY	IN
	DESIRED RADAR ALTITUDE	IN
	PITCH ATTITUDE CORRECTION	OUT
	ACTUAL PRESENT ALTITUDE	IN
	PROGRAMMED PRESENT ALTITUDE	IN
	BAROMETRIC ALTITUDE	IN
Climb/Descend and Cruise Vertical Guidance	TRUE AIRSPEED	IN
	PROGRAMMED TRUE AIRSPEED	IN
	VERTICAL VELOCITY	IN
	PROGRAMMED VERTICAL VELOCITY	IN
	PITCH ATTITUDE CORRECTION	OUT
	VERTICAL POSITION	IN
	VERTICAL VELOCITY	IN
	PITCH ATTITUDE	IN
Weapon Delivery Vertical Guidance	PITCH RATE	IN
	ESTIMATED TIME TO RELEASE	IN
	DESIRED VERTICAL VELOCITY	IN
	DESIRED VERTICAL POSITION	IN
	PITCH ATTITUDE CORRECTION	OUT
	PRESENT HEADING	IN
Weapon Delivery Horizontal Guidance	ESTIMATED TIME TO RELEASE	IN
	DESIRED HEADING	IN
	HEADING CORRECTION	OUT
	RANGE TO MLS LOCATION	IN
	BEARING TO MLS LOCATION	IN
	ELEVATION TO MLS LOCATION	IN
Microwave Landing System Guidance	PROGRAMMED RANGE TO MLS LOCATION	IN
	PROGRAMMED BEARING TO MLS LOCATION	IN
	DESIRED GROUND TRACK	IN
	PRESENT HEADING	IN
	PITCH ATTITUDE CORRECTION	OUT
	HEADING CORRECTION	OUT

II. SNS SIMULATION DATA DEFINITION PROCEDURE

The following major steps are required in preparing SNS input data:

Definition of Mission Scenario

Mission Scenario Segmentation

Mission Segment Functional Definition

Function to Task Assignment

Task to PE Assignment

Message Flow Analysis

Data Coding (per SNS handbook).

The following is a description of the procedure used to obtain the data for the SNS program:

From the assumed mission scenearios, obtain the mission functions required to accomplish the mission and choose the segment to be analyzed. In this case, segment 8 of the strike mission (weapon delivery segment) is selected

From the mission segment operational time table (Table 4), define the algorithms and equipment operating and from the task assignment table (Tables 24, 25) the number of processing elements to be used in the simulation (Table D-4)

The messages required and generated by each task have to be defined (from Table D-2) and labeled depending on whether they are necessary (over 100) or enhancing (over 300) as shown in Figure D-3. Messages of start/end type (task initiation/completion) are labeled under 100, and the number of them must be equal to the number of executing tasks as shown in Figure D-4

Once the above are established, a predecessor/successor relationship flow diagram is needed in order to define the scheduling time for first initiation of each task.

Table D-5 shows the required SNS data for all tasks as obtained by the above mentioned procedure. The data are coded the same way as referred to in the original SNS manual.

TABLE D-4. SNS TASK ID/PE ASSIGNMENT (HYBRID CONFIGURATION)

Task	Task ID	PE Number
Radar Altimeter Subsystem Service (RADALT)	41	3
Inertial Navigation System (INS)	42	2
Radiation Sensor Subsystem Service (RADSNS)	43	6
Air Data (AIRDTA)	45	3
Status Monitor (STATMN)	46	3
Narrowband Data Link Subsystem Service (NBDL)	47	4
Target Position Computation (TGPSCM)	48	6
Impact Point Computation (IMPTCM)	49	6
Navigation Filter (NAVFIL)	50	2
Flight Control (FLTCON)	51	5
Steering (STERNG)	52	3
Guidance (GUIDNC)	53	3
Mission Control (MISCON)	54	3
Wideband Data Link Subsystem Service (WBDL)	55	9
FLIR Subsystem Service (FLIR)	56	8
Weapon Station Subsystem Service (WPNSTN)	57	7
Bus Control (BUSCON)	*	1

*This task is the Global Executive.

TABLE D-5. SNS DATA TABLE

Task ID	Start Time (μs)	Execution Time (μs)	Iteration Time (μs)	Memory (Words)
41	1,000	157	31,250	180
42	2,000	20,313	31,250	3,500
43	3,000	625	250,000	700
45	4,000	1,875	250,000	635
46	5,000	938	1,000,000	1,050
47	6,000	938	62,500	1,050
48	7,000	1,563	62,500	380
49	21,350	22,188	62,500	1,960
50	22,350	N/A	2,000,000	3,600
51	23,350	14,063	31,250	3,350
52	26,150	3,594	62,500	770
53	28,710	2,188	250,000	2,500
54	42,600	4,688	62,500	5,300
55	47,350	157	1,000,000	220
56	48,400	938	62,500	700
57	49,400	938	62,500	650

APPENDIX E
DETAILED RELIABILITY DATA

APPENDIX E

DETAILED RELIABILITY DATA

This appendix contains the detailed reliability tables for the three candidate processing systems.

As stated previously in this report, each of the two distributed networks considered in this study is a homogeneous processing system. In the case of a nonhomogeneous processing system, using a mix of microprocessor types, system reliability could differ from that shown in the following tables. In general, the basic failure rate for an individual processing element varies with the complexity of that element. In most cases, a PE based on a 4-bit or 8-bit microprocessor will have a lower failure rate than a PE based on a 16-bit machine.

In the following tables, where two different PEs contain the same module complement, the failure rates are the same. For example, the Air Data and Radar Altimeter PEs contain the same modules as can be seen from Table 18.

The system level MTBFs shown in Tables E-1 through E-21 are given for each system and mission configuration in three different categories:

Total serial where all parts of the system are considered

Mission success where only mission-critical entities are accounted for

Flight success where only flight-critical parts of the system are considered.

TABLE E-1. RELIABILITY PREDICTION FOR DP/M SYSTEM–STRIKE CONFIGURATION (TOTAL SERIAL)

Name of Functional Element	Core or Mission Peculiar	Failure Rate Per 10^6 Hours $T_A = 45°C$	Failure Rate Per 10^6 Hours $T_A = 80°C$
Bus Control	Core	70.13	110.79
INS	Core	103.31	167.92
Flight Control	Core	80.36	127.8
GPS	Core	146.71	242.06
Mission Control and Status	Core	97.07	160.24
Airdata	Core	58.66	90.73
Aircraft Instrumentation	Core	58.66	90.73
Radar Altimeter	Core	58.66	90.73
MLS	Core	58.66	90.73
Guidance and Steering	Core	74.12	120.12
NBDL	Core	58.66	90.73
IFF	Core	58.66	90.73
Power Supplies	Core	88.22	113.75
Total Failure Rate for Core Functions		1011.88	1587.06
TERCOM	Mission Peculiar	103.31	167.92
Radiation Sensor	Mission Peculiar		
Target Position Computation	Mission Peculiar	80.36	127.8
Impact Point Computation	Mission Peculiar		
Line of Sight	Mission Peculiar		
WBDL	Mission Peculiar	58.66	90.73
FLIR	Mission Peculiar	58.66	90.73
Weapons Station	Mission Peculiar	58.66	90.73
Total Failure Rate for Mission Peculiar Functions		359.65	567.91
Total Failure Rate (Core + Mission Peculiar)		1371.53	2154.97
Strike Mission MTBF = $1/\lambda_T$ =		729 hours	464 hours

TABLE E-2. RELIABILITY PREDICTION FOR HYBRID SYSTEM–STRIKE CONFIGURATION (TOTAL SERIAL)

Name of Functional Element	Core or Mission Peculiar	Failure Rate Per 10^6 Hours $T_A = 45°C$	Failure Rate Per 10^6 Hours $T_A = 80°C$
Bus Control	Core	70.13	110.79
INS	Core	80.36	127.8
Flight Control	Core	80.36	127.8
GPS	Core	146.71	242.06
Mission Control	Core		
Air data	Core		
Aircraft Instrumentation	Core		
Radar Altimeter	Core	125.01	204.99
MLS	Core		
Guidance and Steering	Core		
Status Monitoring	Core		
NBDL	Core		
NAV Filter	Core	114.86	188.13
IFF	Core		
Power Supplies	Core	62.84	79.37
Total Failure Rate for Core Functions		680.27	1080.94
TERCOM	Mission Peculiar	103.31	167.92
Radiation Sensor	Mission Peculiar		
Target Position Computation	Mission Peculiar	80.36	127.8
Impact Point Computation	Mission Peculiar		
Line of Sight	Mission Peculiar		
WBDL	Mission Peculiar	58.66	90.73
FLIR	Mission Peculiar	58.66	90.73
Weapon Station	Mission Peculiar	58.66	90.73
Total Failure Rate for Mission Peculiar Functions		359.65	567.91
Total Failure Rate (Core + Mission Peculiar)		1039.92	1648.85
Strike Mission MTBF = $1/\lambda_T$		962 hours	607 hours

TABLE E-3. RELIABILITY PREDICTION FOR CENTRALIZED SYSTEM–STRIKE CONFIGURATION (TOTAL SERIAL)

Name of Functional Element	Main Computer or Remote Terminal	Failure Rate per 10^6 Hours $T_A = 45°C$	Failure Rate per 10^6 Hours $T_A = 80°C$
MCCR	Main Computer	34.80	48.03
ADDRESS	Main Computer	42.62	50.76
DATA	Main Computer	147.20	202.68
CORE STACK	Main Computer	59.28	73.68
APU	Main Computer	24.08	29.89
MCU	Main Computer	43.30	57.80
FPAPU	Main Computer	35.27	45.46
SERIAL INPUT	Main Computer	13.61	16.61
PARALLEL INPUT	Main Computer	10.86	13.24
SERIAL OUTPUT	Main Computer	14.32	17.82
Interrupt Assy	Main Computer	16.53	20.20
P Bus Decode	Main Computer	11.64	15.58
Power Supply Assy	Main Computer	34.00	46.59
Total Failure Rate for Main Computer		487.51	638.34
Remote Terminals for Following Functions:			
Bulk Storage	Remote Terminal	46.49	68.56
IMU and Remote Compass	Remote Terminal	46.49	68.56
Flight Control	Remote Terminal	46.49	68.56
GPS	Remote Terminal	46.49	68.56
Air data	Remote Terminal		
Aircraft Instrumentation	Remote Terminal	46.49	68.56
Radar Altimeter	Remote Terminal		
MLS	Remote Terminal		
NBDL and IFF Transponder	Remote Terminal	46.49	68.56
TERCOM	Remote Terminal	46.49	68.56
Radiation Sensor	Remote Terminal	46.49	68.56
WBDL	Remote Terminal	46.49	68.56
FLIR	Remote Terminal	46.49	68.56
Weapon Station	Remote Terminal	46.49	68.56
Total Failure Rate for Remote Terminals		511.39	754.16
Total Failure Rate for Main Computer + Terminals		998.9	1392.50
Strike Mission MTBF = $1/\lambda_T$		1001 hours	718 hours

TABLE E-4. RELIABILITY PREDICTION FOR DP/M SYSTEM–STRIKE CONFIGURATION (MISSION SUCCESS)

Name of Functional Element	Core or Mission Peculiar	Failure Rate per 10^6 Hours $T_A = 45°C$	Failure Rate per 10^6 Hours $T_A = 80°C$
Bus Control	Core	70.13	110.79
INS	Core	103.31	167.92
Flight Control	Core	80.36	127.80
GPS	Core	146.71	242.06
Mission Control and Status	Core	97.07	160.24
Air Data	Core	58.66	90.73
Radar Altimeter	Core	58.66	90.73
Guidance and Steering	Core	74.12	120.12
IFF	Core	58.66	90.73
Power Supplies	Core	88.22	113.75
Total Failure Rate for Core Functions Affecting Mission Success		835.9	1314.87
TERCOM	Mission Peculiar	103.31	167.92
Radiation Sensor	Mission Peculiar		
Target Position Computation	Mission Peculiar	80.36	127.8
Impact Point Computation	Mission Peculiar		
Line of Sight	Mission Peculiar		
Weapons Station	Mission Peculiar	58.66	90.73
Total Failure Rate for Mission Peculiar Functions Affecting Mission Success		242.33	386.45
Total Failure Rate for Core + Mission Peculiar Functions Affecting Mission Success		1078.23	1701.32
Strike Mission Success MTBF = $1/\lambda_T$		928 hours	588 hours

TABLE E-5. RELIABILITY PREDICTION FOR HYBRID SYSTEM–STRIKE CONFIGURATION (MISSION SUCCESS)

Name of Functional Element	Core or Mission Peculiar	Failure Rate Per 10^6 Hours $T_A = 45°C$	Failure Rate Per 10^6 Hours $T_A = 80°C$
Bus Control	Core	70.13	110.79
INS	Core	80.36	127.8
Flight Control	Core	80.36	127.8
GPS	Core	146.71	242.06
Mission Control	Core		
Air Data	Core		
Radar Altimeter	Core		
Aircraft Instrumentation	Core	125.01	204.99
MLS	Core		
Guidance and Steering	Core		
Status Monitoring	Core		
Navigation Filter	Core		
IFF	Core	114.86	188.13
NBDL	Core		
Power Supplies	Core	62.84	79.37
Total Failure Rate for Core Functions Affecting Mission Success		680.27	1080.94
TERCOM	Mission Peculiar	103.31	167.92
Radiation Sensor	Mission Peculiar		
Target Position Computation	Mission Peculiar	80.36	127.8
Impact Point Computation	Mission Peculiar		
Line of Sight	Mission Peculiar		
Weapon Station	Mission Peculiar	58.66	90.73
Total Failure Rate for Mission Peculiar Functions Affecting Mission Success		242.33	386.45
Total Failure Rate for Core + Mission Peculiar Functions Affecting Mission Success		922.6	1467.39
Strike Mission Success MTBF = $1/\lambda_T$		1084 hours	682 hours

TABLE E-6. RELIABILITY PREDICTION FOR CENTRALIZED SYSTEM–STRIKE CONFIGURATION (MISSION SUCCESS)

Name of Functional Element	Main Computer or Remote Terminal	Failure Rate Per 10^6 Hours $T_A = 45°C$	Failure Rate Per 10^6 Hours $T_A = 80°C$
Main Computer	Main Computer	487.51	638.34
(Refer to Table E-3 for detailed breakout)			
Remote Terminals for Following Functions:			
Bulk Storage	Remote Terminal	46.49	68.56
IMU & Remote Compass	Remote Terminal	46.49	68.56
Flight Control	Remote Terminal	46.49	68.56
GPS	Remote Terminal	46.49	68.56
Air Data	Remote Terminal		
Aircraft Instrumentation	Remote Terminal	46.49	68.56
Radar Altimeter	Remote Terminal		
MLS	Remote Terminal		
NBDL	Remote Terminal	46.49	68.56
IFF Transponder	Remote Terminal		
TERCOM	Remote Terminal	46.49	68.56
Radiation Sensor	Remote Terminal	46.49	68.56
Weapon Station	Remote Terminal	46.49	68.56
Total Failure Rate for Terminals Affecting Mission Success		418.41	617.04
Total Failure Rate for Main Computer + Terminals Affecting Mission Success		905.92	1255.38
Strike Mission Success MTBF = $1/\lambda_T$		1104 hours	797 hours

TABLE E-7. RELIABILITY PREDICTION FOR DP/M SYSTEM–RECCE CONFIGURATION (TOTAL SERIAL)

Name of Functional Element	Core or Mission Peculiar	Failure Rate Per 10^6 Hours $T_A = 45°C$	$T_A = 80°C$
Core	Core Electronics	1011.88	1587.06
(Refer to Table E-1 for detailed breakout)			
Photocamera	Mission Peculiar	58.66	90.73
IR Line Scanner	Mission Peculiar	58.66	90.73
TERCOM	Mission Peculiar	103.31	167.92
WBDL	Mission Peculiar	58.66	90.73
Total Failure Rate of Mission Peculiar Functions		279.29	440.11
Total Failure Rate of Core + Mission Peculiar Functions		1291.17	2027.17
Recce Mission MTBF = $1/\lambda_T$		775 hours	493 hours

TABLE E-8. RELIABILITY PREDICTION FOR HYBRID SYSTEM–RECCE CONFIGURATION (TOTAL SERIAL)

Name of Functional Element	Core or Mission Peculiar	Failure Rate Per 10^6 Hours $T_A = 45°C$	$T_A = 80°C$
Core	Core	680.27	1080.94
(Refer to Table E-2 for Detailed breakout)			
Photocamera IR Line Scanner	Mission Peculiar	58.66	90.73
TERCOM	Mission Peculiar	103.31	167.92
WBDL	Mission Peculiar	58.66	90.73
Total Failure Rate of Mission Peculiar Functions		220.63	349.38
Total Failure Rate of Core + Mission Peculiar Functions		900.9	1430.32
Recce Mission MTBF = $1/\lambda_T$		1110 hours	699 hours

TABLE E-9. RELIABILITY PREDICTION FOR CENTRALIZED SYSTEM–RECCE CONFIGURATION (TOTAL SERIAL)

Name of Functional Element	Core or Mission Peculiar	Failure Rate Per 10^6 Hours $T_A = 45°C$	Failure Rate Per 10^6 Hours $T_A = 80°C$
Main Computer	Main Computer	487.51	638.34
(Refer to Table E-3 for detailed breakout)			
Remote Terminals for the Following Functions:			
Bulk Storage	Remote Terminal	46.49	68.56
IMU and Remote Compass	Remote Terminal	46.49	68.56
Flight Control	Remote Terminal	46.49	68.56
GPS	Remote Terminal	46.49	68.56
Air Data Aircraft Instrumentation Radar Altimeter MLS	Remote Terminal Remote Terminal Remote Terminal Remote Terminal	46.49	68.56
NBDL IFF Transponder	Remote Terminal Remote Terminal	46.49	68.56
Photo Camera or IR Line Scanner	Remote Terminal Remote Terminal	46.49	68.56
TERCOM	Remote Terminal	46.49	68.56
WBDL	Remote Terminal	46.49	68.56
Total Failure Rate for Remote Terminals		418.41	617.04
Total Failure Rate for Main Computer + Remote Terminals		905.92	1255.38
Recce Mission MTBF = $1/\lambda_T$		1104 hours	797 hours

TABLE E-10. RELIABILITY PREDICTION FOR DP/M SYSTEM–REECE CONFIGURATION (MISSION SUCCESS)

Name of Functional Element	Core or Mission Peculiar	Failure Rate Per 10^6 Hours $T_A = 45°C$		Failure Rate Per 10^6 Hours $T_A = 80°C$	
Bus Control	Core	70.13		110.79	
INS	Core	103.31		167.92	
Flight Control	Core	80.36		127.8	
GPS	Core	146.71		242.06	
Mission Control and Status	Core	97.07		160.24	
Air Data	Core	58.66		90.73	
Radar Altimeter	Core	58.66		90.73	
Guidance and Steering	Core	74.12		120.12	
IFF	Core	58.66		90.73	
Power Supplies	Core	79.76		102.29	
Total Failure Rate of Core Functions Affecting Recce Mission Success		827.43		1303.41	
IR Scanner (operating redundancy)	Mission Peculiar	58.66	λeff =	90.73	λeff =
WBDL (operating redundancy)	Mission Peculiar	58.66	50.28	90.73	77.7
Photo camera (operating redundancy)	Mission Peculiar	58.66		90.73	
TERCOM	Mission Peculiar	103.31		167.92	
Total Failure Rate of Mission Peculiar Functions Affecting Mission Success		153.59		245.62	
Total Failure Rate of Core + Mission Peculiar Functions Affecting Mission Success		981.02		1549.03	
Recce Mission Success MTBF		1019 hours		646 hours	

TABLE E-11. RELIABILITY PREDICTION FOR HYBRID SYSTEM–RECCE CONFIGURATION (MISSION SUCCESS)

Name of Functional Element	Core or Mission Peculiar	Failure Rate Per 10^6 Hours $T_A = 45°C$	Failure Rate Per 10^6 Hours $T_A = 80°C$
Bus Control	Core	70.13	110.79
INS	Core	80.36	127.8
Flight Control	Core	80.36	127.8
GPS	Core	146.71	242.06
Mission Control Air Data Radar Altimeter Guidance and Steering Status Monitoring	Core Core Core Core Core	125.01	204.99
NAV Filter	Core	114.86	188.13
Power Supplies	Core	62.84	79.37
Total Failure Rate of Core Functions Affecting Mission Success		680.27	1080.94
IR Scanner Photo Camera	Mission Peculiar Mission Peculiar	58.66	90.73
WBDL	Mission Peculiar	58.66	90.73
TERCOM	Mission Peculiar	103.31	167.92
Total Failure Rate of Mission Peculiar Functions		220.63	349.38
Total Failure Rate of Core + Mission Peculiar Functions Affecting Recce Mission Success		900.9	1430.32
Recce Mission MTBF = $1/\lambda_T$		1110 hours	699 hours

TABLE E-12. RELIABILITY PREDICTION FOR CENTRALIZED SYSTEM–RECCE CONFIGURATION (MISSION SUCCESS)

Name of Functional Element	Main Computer or Remote Terminal	Failure Rate Per 10^6 Hours $T_A = 45°C$	Failure Rate Per 10^6 Hours $T_A = 80°C$
Main Computer (Refer to Table E-3 for detailed breakout)	Main Computer	487.51	638.34
Remote Terminals for the Following Functions:			
Bulk Storage	Remote Terminal	46.49	68.56
IMU and Remote Compass	Remote Terminal	46.49	68.56
Flight Control	Remote Terminal	46.49	68.56
GPS	Remote Terminal	46.49	68.56
Air Data Aircraft Instrumentation Radar Altimeter MLS	Remote Terminal Remote Terminal Remote Terminal Remote Terminal	46.49	68.56
NBDL IFF Transponder	Remote Terminal Remote Terminal	46.49	68.56
Photo Camera or IR Line Scanner	Remote Terminal Remote Terminal	46.49	68.56
TERCOM	Remote Terminal	46.49	68.56
Total Failure Rate for Remote Terminals Affecting Mission Success		371.92	548.48
Total Failure Rate for Main Computer + Remote Terminals Affecting Recce Mission Success		859.43	1186.82
Recce Mission Success MTBF = $1/\lambda_T$		1164 hours	843 hours

TABLE E-13. RELIABILITY PREDICTION FOR DP/M SYSTEM–EW CONFIGURATION (TOTAL SERIAL)

Name of Functional Element	Core or Mission Peculiar	Failure Rate Per 10^6 Hours $T_A = 45°C$	Failure Rate Per 10^6 Hours $T_A = 80°C$
Core	Core	1011.88	1587.06
(Refer to Table E-1 for detailed breakout)			
Active Jam Control	Mission Peculiar	58.66	90.73
Threat Warning Receiver	Mission Peculiar	58.66	90.73
Chaff Dispenser	Mission Peculiar	58.66	90.73
Total Failure Rate of Mission Peculiar Functions		175.98	272.19
Total Failure Rate of Core + Mission Peculiar Functions		1187.86	1859.25
EW Mission MTBF = $1/\lambda_T$		842 hours	538 hours

TABLE E-14. RELIABILITY PREDICTION FOR HYBRID SYSTEM–EW CONFIGURATION (TOTAL SERIAL)

Name of Functional Element	Core or Mission Peculiar	Failure Rate Per 10^6 Hours $T_A = 45°C$	Failure Rate Per 10^6 Hours $T_A = 80°C$
Core	Core	680.27	1080.94
(Refer to Table E-2 for detailed breakout)			
Active Jam Control Threat Warning Receiver	Mission Peculiar	80.36	127.8
Chaff Dispenser	Mission Peculiar	58.66	90.73
Total Failure Rate for Mission Peculiar Functions		139.02	218.53
Total Failure Rate of Core + Mission Peculiar Functions		819.29	1299.47
EW Mission MTBF = $1/\lambda_T$		1221 hours	770 hours

TABLE E-15. RELIABILITY PREDICTION FOR CENTRALIZED SYSTEM–EW CONFIGURATION (TOTAL SERIAL)

Name of Functional Element	Main Computer or Remote Terminal	Failure Rate Per 10^6 Hours $T_A = 45°C$	Failure Rate Per 10^6 Hours $T_A = 80°C$
Main Computer	Main Computer	487.51	638.34
(Refer to Table E3 for detailed breakout)			
Remote Terminals for Following Functions:			
Bulk Storage	Remote Terminal	46.49	68.56
IMU and Remote Compass	Remote Terminal	46.49	68.56
Flight Control	Remote Terminal	46.49	68.56
GPS	Remote Terminal	46.49	68.56
Air Data	Remote Terminal		
Aircraft Instrumentation	Remote Terminal	46.49	68.56
Radar Altimeter	Remote Terminal		
MLS	Remote Terminal		
NBDL	Remote Terminal	46.49	68.56
IFF Transponder	Remote Terminal		
Active Jammer	Remote Terminal	46.49	68.56
Threat Warning Receiver	Remote Terminal	46.49	68.56
Chaff Dispenser	Remote Terminal	46.49	68.56
Total Failure Rate for Terminals		418.41	617.04
Total Failure Rate for Main Computer + Remote Terminals		905.92	1255.38
EW Mission MTBF = $1/\lambda_T$		1104 hours	797 hours

TABLE E-16. RELIABILITY PREDICTION FOR DP/M SYSTEM–EW CONFIGURATION (MISSION SUCCESS)

Name of Functional Element	Core or Mission Peculiar	Failure Rate Per 10^6 Hour $T_A = 45°C$	$T_A = 80°C$
Bus Control	Core	70.13	110.79
INS	Core	103.31	167.92
Flight Control	Core	80.36	127.8
GPS	Core	146.71	242.06
Mission Control and Status	Core	97.07	160.24
Air Data	Core	58.66	90.73
Radar Altimeter	Core	58.66	90.73
Guidance and Steering	Core	74.12	120.12
IFF	Core	58.66	90.73
Power Supplies	Core	79.76	102.29
Total Failure Rate of Core Functions Affecting Mission Success		827.43	1303.41
Chaff Dispenser	Mission Peculiar	58.66	90.73
Total Failure Rate of Core + Mission Peculiar Functions Affecting EW Mission Success		886.09	1394.14
EW Mission Success MTBF ≈ $1/\lambda_T$		1129 hours	717 hours

TABLE E-17. RELIABILITY PREDICTION FOR HYBRID SYSTEM–EW CONFIGURATION (MISSION SUCCESS)

Name of Functional Element	Core or Mission Peculiar	Failure Rate Per 10^6 Hours $T_A = 45°C$	Failure Rate Per 10^6 Hours $T_A = 80°C$
Bus Control	Core	70.13	110.79
INS	Core	80.36	127.8
Flight Control	Core	80.36	127.8
GPS	Core	146.71	242.06
Mission Control	Core		
Air Data	Core		
Radar Altimeter	Core	125.01	204.99
Guidance and Steering	Core		
Status Monitoring	Core		
NAV Filter	Core	114.86	188.13
Power Supplies	Core	62.84	79.37
Total Failure Rate for Core Functions Affecting Mission Success		680.27	1080.94
Chaff Dispenser	Mission Peculiar	58.66	90.73
Total Failure Rate for Core and Mission Peculiar Functions Affecting E.W. Mission Success		738.93	1171.67
EW Mission Success MTBF = $1/\lambda_T$		1353 hours	854 hours

TABLE E-18. RELIABILITY PREDICTION FOR CENTRALIZED SYSTEM–EW CONFIGURATION (MISSION SUCCESS

Name of Functional Element	Main Computer or Remote Terminal	Failure Rate Per 10^6 Hours $T_A = 45°C$	Failure Rate Per 10^6 Hours $T_A = 80°C$
Main Computer	Main Computer	487.51	638.34
(Refer to Table E-3 for detailed breakout)			
Remote Terminals for the Following Functions:			
Bulk Storage	Remote Terminal	46.49	68.56
IMU and Remote Compass	Remote Terminal	46.49	68.56
Flight Control	Remote Terminal	46.49	68.56
GPS	Remote Terminal	46.49	68.56
Air Data	Remote Terminal		
Aircraft Instrumentation	Remote Terminal		
Radar Altimeter	Remote Terminal	46.49	68.56
MLS	Remote Terminal		
NBDL	Remote Terminal	46.49	68.56
IFF Transponder	Remote Terminal		
Chaff Dispenser	Remote Terminal	46.49	68.56
Total Failure Rate for Remote Terminals Affecting Mission Success		325.43	479.92
Total Failure Rate for Main Computer + Remote Terminal Affecting EW Mission Success		812.94	1118.26
EW Mission Success MTBF = $1/\lambda_T$		1230 hours	894 hours

TABLE E-19. RELIABILITY PREDICTION FOR SAFE FLIGHT OF AIRCRAFT–DP/M SYSTEM

Name of Functional Element	Core or Mission Peculiar	Failure Rate Per 10^6 Hours $T_A = 45°C$	Failure Rate Per 10^6 Hours $T_A = 80°C$
Bus Control	Core	70.13	110.79
INS	Core	103.31	167.92
Flight Control	Core	80.36	127.8
Mission Control and Status	Core	97.07	160.24
Air Data	Core	58.66	90.73
Guidance and Steering	Core	74.12	120.12
IFF	Core	58.66	90.73
Power Supplies	Core	88.22	113.75
Total Failure Rate		630.53	982.08
Safety of Flight MTBF = $1/\lambda_T$		1586 hours	1018 hours

TABLE E-20. RELIABILITY PREDICTION FOR SAFE FLIGHT OF AIRCRAFT–HYBRID SYSTEM

Name of Functional Element	Core or Mission Peculiar	Failure Rate Per 10^6 Hours $T_A = 45°C$	$T_A = 80°C$
Bus Control	Core	70.13	110.79
INS	Core	80.36	127.8
Flight Control	Core	80.36	127.8
Mission Control	Core		
Air Data	Core		
Guidance and Steering	Core	125.01	204.99
Status Monitoring	Core		
NBDL	Core		
NAV Filter	Core	114.86	188.13
IFF	Core		
Power Supplies	Core	62.84	79.37
Total Failure Rate		533.56	838.88
Safety of Flight MTBF = $1/\lambda_T$		1874 hours	1192 hours

TABLE E-21. RELIABILITY PREDICTION FOR SAFE FLIGHT OF AIRCRAFT–CENTRALIZED SYSTEM

Name of Functional Element	Main Computer or Remote Terminal	Failure Rate Per 10^6 Hours $T_A = 45°C$	$T_A = 80°C$
Main Computer	Main Computer	487.51	638.34
(Refer to Table E-3 for detailed breakout)			
Remote Terminals for the Following Functions:			
IMU and Remote Compass	Remote Terminal	46.49	68.56
Flight Control	Remote Terminal	46.49	68.56
Radar Altimeter	Remote Terminal		
Air Data	Remote Terminal	46.49	68.56
Aircraft Instrumentation	Remote Terminal		
MLS	Remote Terminal		
NBDL and	Remote Terminal	46.49	68.56
IFF Transponder	Remote Terminal		
Total Failure Rate for Remote Terminals Affecting Safety of Flight		185.96	274.24
Total Failure Rate of Main Computer + Remote Terminals Affecting Safety of Flight		673.47	912.58
Safety of Flight MTBF = $1/\lambda_T$		1485 hours	1096 hours

APPENDIX F
PROCESSING SYSTEM LCC MODEL

APPENDIX F

PROCESSING SYSTEM LCC MODEL

I. GENERAL

The life-cycle cost (LCC) model which was employed in the ARPV study is summarized by the block diagram in Figure F-1. The total cumulative life cycle cost at the end of "T" years is the sum of the acquisition cost (CACQ) and sustaining cost (CSUS) as shown in this figure. The following sections contain a block-by-block discussion of each cost category appearing in Figure F-1.

II. ACQUISITION COST

A. DESIGN AND DEVELOPMENT COST

The design and development cost is given by the following equation.

$$CDAD = CDADP + CDADPS + CDADS + CDADSS \tag{F-1}$$

where

CDAD = design and development (D&D) cost

CDADP = prime equipment D&D cost (hardware)

CDADPS = prime equipment D&D cost (software)

CDADS = support equipment D&D cost (hardware)

CDADSS = support equipment D&D cost (software).

B. NONRECURRING INVESTMENT COSTS

The nonrecurring investment costs consist of the initial provisioning cost, initial training cost, and initial technical data cost.

1. Initial Provisioning Cost

$$CIP = XLII \cdot CPLII \tag{F-2}$$

where

CIP = initial provisioning cost

XLII = number of line items introduced into the supply system

CPLII = cost per line item introduction.

2. Initial Training Cost

$$CIT = XMTI \cdot CITC \tag{F-3}$$

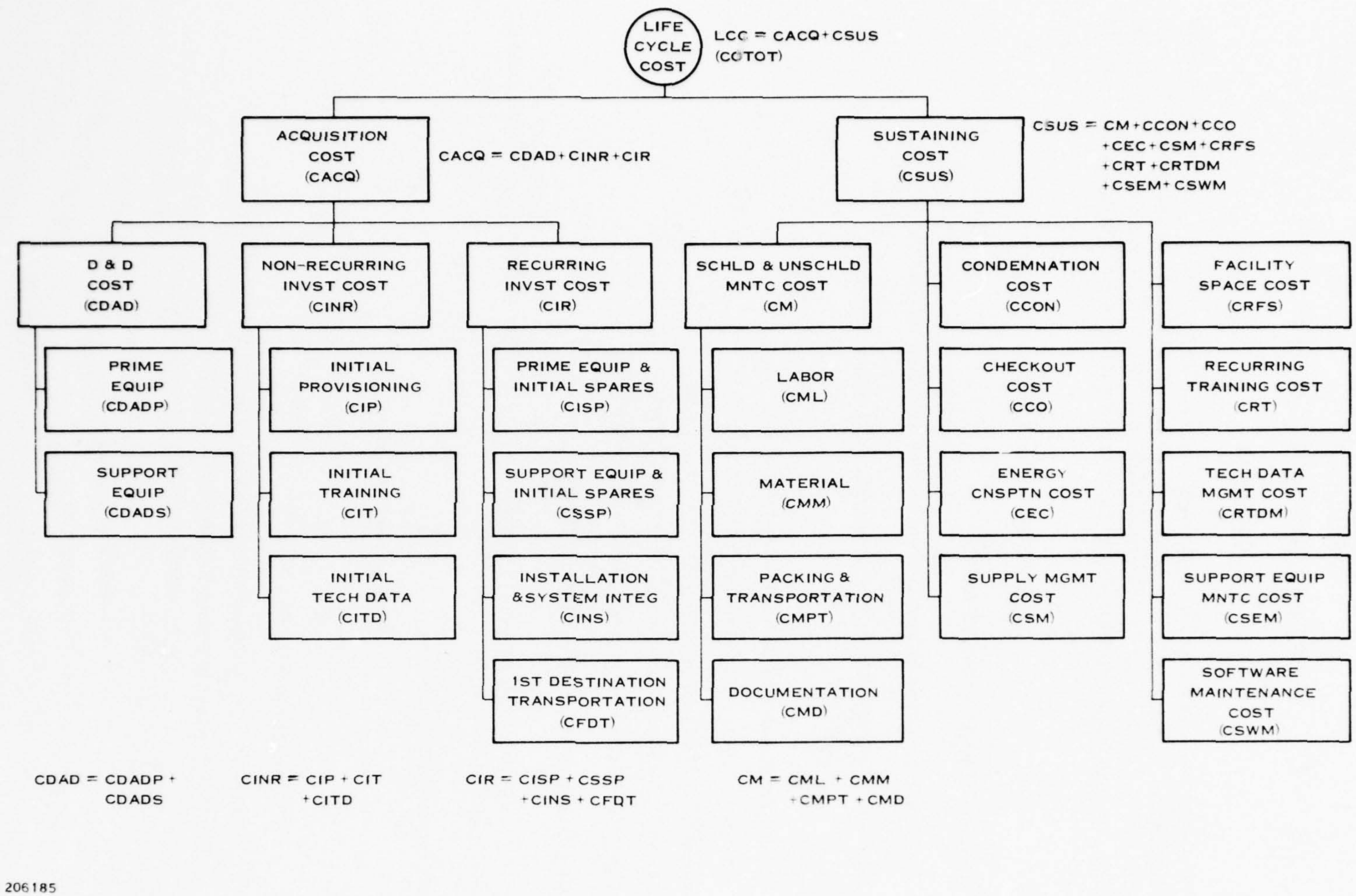

Figure F-1. ARPV Processor LCC Model

where

$$CIT = \text{initial training cost}$$
$$XMTI = \text{number of instructors initially trained}$$
$$CITC = \text{initial training course cost per student.}$$

3. Initial Technical Data Cost

$$CITD = XTDPC \cdot (CPPC + CRPD) \tag{F-4}$$

where

$$CITD = \text{initial technical data cost}$$
$$XTDPC = \text{number of unique technical data pages created}$$
$$CPPC = \text{cost of creating a page of technical data}$$
$$CRPD = \text{cost of technical data reproduction per page.}$$

4. Nonrecurring Investment Cost

$$CINR = CIP + CIT + CITD \tag{F-5}$$

where

$$CINR = \text{nonrecurring investment cost}$$
$$CIP = \text{initial provisioning cost}$$
$$CIT = \text{initial training cost}$$
$$CITD = \text{initial technical data cost.}$$

C. RECURRING INVESTMENT COSTS

The recurring investment costs include the costs of the prime and support equipments and initial spares, installation cost, and cost of first destination transportation.

1. Installation Costs

$$CINS = XHLI \cdot XR(I) + CMIH \tag{F-6}$$

where

$$CINS = \text{installation cost per equipment}$$
$$XHLI = \text{manhours of installation labor per equipment}$$
$$XR(I) = \text{labor rate per manhour for installation personnel}$$
$$CMIH = \text{material cost of aircraft interface hardware.}$$

2. **First-Destination Transportation Cost**

$$CFDT = WPEISC \cdot ANMFD \cdot CPPPMT + CPPE \cdot WPEISC \qquad (F\text{-}7)$$

where

CFDT = first-destination transportation cost

WPEISC = weight of equipment and initial spares plus container

ANMFD = average one-way distance, from origin to destination

CPPPMT = cost for transportation of equipment per pound per mile

CPPE = cost of packing equipment–including labor and materials.

3. **Prime Equipment and Initial Spares**

$$CISP_i = XP_i\ (CUNITP_i + CUNITS_i + CPEIS_i + CINS + CFDT) \qquad (F\text{-}8)$$

where

$CISP_i$ = cost of prime equipment and initial spares in *ith* year

XP_i = number of prime equipment acquired in *ith* year

$CUNITP_i$ = prime equipment (software) unit cost in *ith* year

$CPEIS_i$ = prime equipment initial spares cost in *ith* year

CINS = installation cost per equipment

CFDT = first-destination transportation cost per equipment.

4. **Support Equipment and Initial Spare**

a. ***Flight Line AGE***

$$CFL_i = XOS_i\ (CNITO_i + CISTO_i) \qquad (F\text{-}9)$$

where

CFL_i = cost of flight-line or organizational level AGE

XOS_i = number of sets of flight-line AGE acquired during *ith* year

$CNITO_i$ = average unit cost of flight-line AGE acquired in *ith* year

$CISTO_i$ = flight-line AGE initial spares cost–percent of unit cost–in *ith* year.

b. ***Intermediate-Level AGE***

$$CIT_i = XIS_i\ (CNITI_i + CISTI_i) \qquad (F\text{-}10)$$

where

CIT_i = cost of intermediate-level AGE

XIS_i = number of sets of intermediate-level AGE acquired during *ith* year

$CNITI_i$ = average unit cost of intermediate-level AGE acquired in *ith* year

$CISTI_i$ = intermediate-level AGE initial spares cost—percent of unit cost—in *ith* year.

c. ***Depot-Level AGE***

$$CDI_i = XDS_i\,(CNITD_i + CISTD_i) \qquad \text{(F-11)}$$

where

CID_i = cost of depot-level AGE

XDS_i = number of sets of depot-level AGE acquired during *ith* year

$CNITD_i$ = average unit cost of depot-level AGE acquired in *ith* year

$CISTD_i$ = depot-level AGE initial spares cost—percent of unit cost—in *ith* year.

d. ***Support Equipment and Initial Spares***

$$CSSP_i = CFL_i + CIL_i + CID_i \qquad \text{(F-12)}$$

where

$CSSP_i$ = cost of support equipment and initial spares

CFL_i = cost of flight-line AGE

CIL_i = cost of intermediate-level AGE

CID_i = cost of depot-level AGE.

5. **Recurring Investment Costs**

$$CIR = CISP_i + CSSP_i \qquad \text{(F-13)}$$

where

CIR = recurring investment costs

$CISP_i$ = prime equipment and initial spares cost

$CSSP_i$ = support equipment and initial spares cost

D. ACQUISITION COST

The acquisition cost is the arithmetic sum of D&D and nonrecurring and recurring investment costs.

$$CACQ_i = CDAD + CINR + CIR \tag{F-14}$$

where

$CACQ_i$ = acquisition cost during *ith* year

$CDAD$ = design and development cost

$CINR$ = nonrecurring investment cost

CIR = recurring investment cost.

III. SUSTAINING COSTS

The sustaining costs are the sums of scheduled and unscheduled maintenance, condemnation, checkout, energy consumption, supply management, annual maintenance facility space, annual training, annual recurring technical data management, annual recurring support equipment maintenance, and annual software costs.

A. SCHEDULED AND UNSCHEDULED MAINTENANCE COSTS

1. Unscheduled (Random) Maintenance Costs

a. Random Maintenance Labor

$$CRML = \frac{OTPYX}{XTBM}\left(\sum_{i=1}^{3} XK_i \cdot AMHMA_i \cdot XR_i\right) \tag{F-15}$$

where

$CRML$ = random maintenance labor cost

$OTPYX$ = average operating time per equipment per year (including checkout)

$XTBM$ = system mean time between random maintenance actions

XK_i = percent of system failures requiring labor at organization, intermediate, and depot levels

$AMHMA_i$ = average repair time, in manhours, per maintenance action for organizational, intermediate, and depot level repairs

XR_i = labor rate per manhour for organizational, intermediate, and depot maintenance levels.

b. Random Maintenance Material

$$CRMM = \frac{OTPYX}{XTBF}\left(\sum_{i=1}^{3} XKK_i \cdot CMARA_i\right) \qquad (F\text{-}16)$$

where

CRMM = random maintenance material cost

OTPYX = average operating time per equipment per year (including checkout)

XTBF = system mean time between random failures

XKK_i = percent of system failures requiring material at organizational, intermediate, and depot levels of repair

$CMARA_i$ = average material cost per random maintenance repair action at organizational, intermediate and depot levels

c. Random Maintenance Documentation Cost

$$CRMD = \frac{OTPYX}{XTBM} \cdot CAMD \qquad (F\text{-}17)$$

where

CRMD = random maintenance documentation cost

OTPYX = average operating time per equipment per year (including checkout)

XTBM = system mean time between random maintenance actions

CAMD = average cost of maintenance documentation per maintenance action.

d. Random Maintenance Packaging and Transportation Cost

$$CRMPAT = \frac{OTPYX}{XTBF} \cdot XK+(WASID \cdot ANMID \cdot CPPPMT + CPPFI \cdot WASID) \qquad (F\text{-}18)$$

where

CRMPAT = random maintenance packaging and transportation costs

OTPYX = average operating time per system per year (including checkout)

XK3 = percent of system failures requiring labor at depot repair

WASID = average shipping weight for depot level repairable items

ANMID = average two-way distance from intermediate level to depot

CPPPMT = cost per equipment per pound per mile for transportation of repairable items

CPPFI = packaging cost for depot repairable items.

e. Random Maintenance Cost

$$CRM = CRML + CRMM + CRMD + CRMPAT \tag{F-19}$$

where

CRM = random maintenance cost

CRML = random maintenance labor cost

CRMM = random maintenance material cost

CRMD = random maintenance documentation cost

CRMPAT = random maintenance packaging and transportation cost.

2. Scheduled (Preventive) Maintenance Cost

a. Preventive Maintenance Cost

$$CPML = \sum_{j=1}^{m} \frac{OTPY_j}{PMI_j} \cdot PMMH_j \cdot PMLR_j \tag{F-20}$$

where

CPML = preventive maintenance labor cost

m = number of different scheduled maintenance actions

$OTPY_j$ = operating time per year for *jth* schedules maintenance item

PMI_j = scheduled maintenance interval for *jth* item

$PMMH_j$ = manhours per maintenance action for *jth* item

$PMLR_j$ = appropriate labor rate for scheduled maintenance of *jth* item.

b. Preventive Maintenance Material Cost

$$CPMM = \sum_{j=1}^{m} \frac{OTPY_j}{PMI_j} \cdot CMP_j \tag{F-21}$$

where

$CPMM$ = preventive maintenance material cost

m = number of different scheduled maintenance actions

$OTPY_j$ = operating time per year for *jth* scheduled maintenance item

PMI_j = scheduled maintenance interval for *jth* item

CMP_j = material cost per scheduled maintenance item j.

c. ***Preventive Maintenance Documentation Cost***

$$CPMD = \sum_{j=1}^{m} \frac{OTPY_j}{PMI_j} \cdot CAMD \qquad \text{(F-22)}$$

where

$CPMD$ = preventative maintenance documentation cost

m = number of different scheduled maintenance actions

$OTPY_j$ = operating time per year for *jth* scheduled maintenance item

PMI_j = scheduled maintenance interval for *jth* item

$CAMD$ = average cost of maintenance documentation per maintenance action.

d. ***Preventive Maintenance Packaging and Transportation Cost***

$$CPMAT = \sum_{j=1}^{nn} \frac{OTPY_j}{PMI_j} \left(WASIDP_j \cdot ANMID \cdot CPPPMT + CPPPI_j \cdot WASIDP_j\right) \qquad \text{(F-23)}$$

where

$CPMPAT$ = preventive maintenance packaging and transportation cost

nn = number of different scheduled maintenance items required at depot

$OTPY_j$ = operating time per year for *jth* scheduled maintenance item

PMI_j = scheduled maintenance interval for *jth* item

$WASIDP_j$ = shipping weight of *jth* scheduled maintenance item

$ANMID$ = average two-way distance from intermediate level to depot

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CPPPMT = cost per equipment per pound per mile for transportation for repairable items

$CPPPI_j$ = packaging cost per *jth* scheduled maintenance item.

e. *Preventive Maintenance Cost*

$$CPM = CPML + CPMM + CPMD + CPMPAT \qquad (F\text{-}24)$$

where

CPM = preventive maintenance cost

CPML = preventive maintenance labor cost

CPMM = preventive maintenance material cost

CPMD = preventive maintenance documentation cost

CPMPAT = preventive maintenance packaging and transportation cost.

3. Scheduled/Unscheduled Maintenance Cost

$$CM = CRM + CPM \qquad (F\text{-}25)$$

where

CM = scheduled/unscheduled maintenance cost
CRM = random (unscheduled) maintenance cost

CPM = preventive (scheduled) maintenance cost.

B. CONDEMNATION COST

The condemnation cost results from attrition or loss of equipment by any of a number of reasons. The equation for condemnation cost is

$$CCON = XK7\ (CUNITP + CUNITS) \qquad (F\text{-}26)$$

where

CCON = condemnation cost

XK7 = percent of equivalent equipments condemned through attrition per year

CUNITP = prime equipment hardware unit cost

CUNITS = prime equipment software unit cost.

C. CHECKOUT COST

The checkout cost is the cost associated with checkout of the equipment. The equation for checkout cost is

$$CCO = XHCEM \cdot 12 \cdot XR1 \qquad \text{(F-27)}$$

where

CCO = checkout cost

XHCEM = manhours of checkout time per equipment per month

XR1 = labor rate per man at flight-line.

D. ENERGY CONSUMPTION COST

The energy consumption cost is given by

$$CEC = \frac{OTPYX \cdot EDC}{EOL} \cdot CEPOH \qquad \text{(F-28)}$$

whe.

CEC = energy consumption cost

OTPYX = average operating time per system per year (including checkout)

EDC = equipment duty cycle

EOL = equipment operating life

CEPOH = cost of energy per operating interval.

E. SUPPLY MANAGEMENT COST

The cost of maintaining and supplying logistical management support is given by

$$CSM = XLIM\ (CLIM + XMSTSX \cdot CLSFSA) \qquad \text{(F-29)}$$

where

CSM = cost of supply management

XLIM = total number of line items managed

CLIM = annual central administration cost of supply management per line item

XMSTSX = number of different intermediate and depot maintenance sites

CLSFSA = cost per line item per site per year for field supply administration.

F. ANNUAL MAINTENANCE FACILITY SPACE COST

The annual maintenance facility space cost is given by

$$CRFS = XMSTSX \cdot FSPSA \cdot CAFS \tag{F-30}$$

where

CRFS = annual maintenance facility space cost

XMSTSX = number of different intermediate and depot maintenance sites

FSPSA = average square feet of floor space per maintenance site devoted to this equipment

CAFS = average cost of space per square foot per year.

G. ANNUAL RECURRING TRAINING COST

The annual recurring or replacement training cost for base and depot maintenance personnel is given by

$$CRT = XNMTB \cdot XATB \cdot CRTCB + XNMTD \cdot XATD \cdot CTRCD \tag{F-31}$$

where

CRT = cost of annual replacement training

XNMTB = total number of base maintenance personnel supporting this equipment

XATB = base maintenance personnel turnover rate per year

CRTCB = recurring training course cost per student per year

XNMTD = total number of depot maintenance personnel supporting this equipment

XATD = depot maintenance personnel turnover rate per year

CRTCD = recurring training course cost per student per year.

H. ANNUAL RECURRING TECHNICAL DATA MANAGEMENT COST

The annual recurring technical data management cost is given by

$$CRTDM = XPMT \cdot CPPTDM \tag{F-32}$$

where

CRTDM = cost of annual recurring technical data management

XPMT = total number of unique technical data pages required for equipment support

CPPPMT = cost of technical data management per page per year.

I. ANNUAL RECURRING SUPPORT EQUIPMENT MAINTENANCE COST

The annual recurring support equipment maintenance cost is given by

$$CSEM = K8(XOSO_i \cdot CNITO_i + XISO_i \cdot CNITI_i + XDSO_i \cdot CNITD_i) \qquad \text{(F-33)}$$

where

$CSEM$ = annual recurring support equipment maintenance cost

$K8$ = support equipment maintenance rate per year expressed as a percentage of unit cost

$XOSO_i$ = total number of organizational level AGE sets

$CNITO_i$ = unit cost of organizational level AGE sets

$XISO_i$ = total number of intermediate level AGE sets

$CNITI_i$ = unit cost of intermediate level AGE sets

$XDSO_i$ = total number of depot level AGE sets

$CNITD_i$ = unit cost of depot level AGE sets.

J. SOFTWARE MAINTENANCE COST

The software maintenance cost (CSWM) is not set forth in a mathematical model, but is an engineering estimated value.

K. SUSTAINING COST SUMMARY

The sustaining cost is given by summing up the following.

$$\begin{aligned} CSUS_i = \; & CNP_i\,(CM + CCON + CCO + CEC) + CSM + CRFS + CRT \\ & + CRTDM + CSEM + CSWM \end{aligned} \qquad \text{(F-34)}$$

where

$CSUS_i$ = annual sustaining cost in *ith* year

CNP_i = number of operating systems in the *ith* year

CM = scheduled and unscheduled maintenance cost

$CCON$ = condemnation cost

CCO = checkout cost

CEC = energy consumption cost

CSM = annual supply maintenance cost

$CRFS$ = annual facility space cost

CRT = annual recurring training cost

CRTDM = annual technical data management cost

CSEM = annual support equipment maintenance cost

CSWM = annual software maintenance cost.

IV. LIFE-CYCLE COST OR CUMULATIVE COST OF OWNERSHIP

The life cycle cost (LCC) or cumulative cost of ownership (COTOT) is given by the following equation.

$$LCC = COTOT = \sum_{i=1}^{t} (CACQ_i + CSUS_i) \tag{F-35}$$

where

LCC = life-cycle cost at the end of T years

$CACQ_i$ = acquisition cost during the *ith* year

$CSUS_i$ = sustaining cost during the *ith* year

t = years of equipment in the inventory (t = T for the last program year).

APPENDIX G

LCC ANALYSIS DATA AND DATA SOURCES

APPENDIX G

LCC ANALYSIS DATA AND DATA SOURCES

The data contained in this appendix was used in the LCC analysis in Section IV of this report. This data resulted from cost estimates and analysis techniques employed by Texas Instruments engineering, logistical, training, technical publications, reliability, maintainability, and logistical support staffs. In some instances, data was acquired from the Air Force and other sources. Such data includes details of the ARPV operational scenario, AFLC logistical support cost model, and AFLC standard cost factors.

APPENDIX G. LCC ANALYSIS DATA AND DATA SOURCES

The data used in the ARPV processor life-cycle cost analysis is cited below along with the data source or reference.

Parameter	Value for Strike-Centralized	Strike-Hybrid	Strike-DP/M	Source
CDADP	\$370,591	\$435,899	\$435,899	Engineering Estimates
CDADPS	\$1,241,484	\$1,493,601	\$1,493,601	Engineering Estimates
CDADS	\$429,158	\$455,256	\$455,256	Engineering Estimates
CDADSS	0	0	0	Engineering Estimates
XLII, XLIM	450 line items	340 line items	340 line items	Logistics Estimates
CPLII	\$40.91/line item	\$40.91/line item	\$40.91/line items	AFLC Standard Cost Factor
XMTI	27 instructors	27 instructors	27 instructors	Training Estimate
CITC	\$4,260/instructor	\$4,260/instructor	\$4,260/instructor	Training Estimate
XTDPC, XPMT	11,748 pages	10,530 pages	10,530 pages	Technical Publications Estimate
(CPPC + CRPP)	\$175/page	\$175/page	\$175/page	Technical Publications Estimate
CUNITP	\$174,941 (2) \$102,902 (3)	\$98,662 (2) \$58,020 (3)	\$150,746 (2) \$85,429 (3)	Engineering Estimates
CUNITS	0	0	0	Engineering Estimates
CPEIS	\$34,988 (2)	\$19,732 (2)	\$30,149 (2)	20% of Unit Cost
XP_i	55 systems/year (2) 275 systems/year (3)	55 systems/year (2) 275 systems/year (3)	55 systems/year (2) 275 systems/year (3)	USAF
XHLI	2.0 hours	2.0 hours	2.0 hours	M estimate
CMIH	0	0	0	Engineering Estimate
WPEISC	150 pounds	160 pounds	248 pounds	Engineering Estimate
ANMFD	1,000 miles	1,000 miles	1,000 miles	USAF Estimate
CPPPMT	\$0.00014/lb./mile	\$0.00014/lb. mile	\$0.00014/lb. mile	Various LCC Models, Factors
CPPE, CPPFI	\$0.53/pound	\$0.53/pound	\$0.53/pound	AFLC Standard Cost Factor
XOS_i, $XOSO_i$	3,0,0,0,0,0,0,0,0,0	3,0,0,0,0,0,0,0,0,0	3,0,0,0,0,0,0,0,0,0	USAF Estimate
$CNITO_i$	\$8,850,0 . . .,0	\$8,850,0, . . .,0	\$8,850,0 . . .,0	Engineering Estimate
$CISTO_i$	\$1,770,0,0, . . . ,0	\$1,770,0,0, . . . ,0	\$1,770,0,0, . . . ,0	20% of Unit Cost Estimate

Parameter	Value for Strike-Centralized	Strike-Hybrid	Strike-DP/M	Source
XDS_i, $XDSO_i$	1,0,0,0,0,0,0,0,0,0	1,0,0,0,0,0,0,0,0,0	1,0,0,0,0,0,0,0,0,0	M estimate
$CNITD_i$	\$71,564,0, . . . , ,0	\$77,279,0, . . . ,0	\$77,279,0, . . . ,0	Engineering Estimate
$CISTD_i$	\$7,156,0, . . . ,0	\$7,728,0, . . . ,0	\$7,758,0, . . . ,0	10% of Unit Cost Estimate
OTPYX	1.5 hour/year	1.5 hour/year	1.5 hour/year	Operation scenario
XTBM	144 hours	121 hours	88 hours	R MTBF estimate with K-factor = 4
XK_i (i = 1)	100%	100%	100%	M estimate
(i = 2)	80%	80%	80%	M estimate
(i = 3)	70%	50%	50%	M estimate
AMHMA (i = 1)	0.5 hour	0.25 hour	0.25 hour	M estimate
(i = 2)	1.0 hour	0.5 hour	0.5 hour	M estimate
(i = 3)	0.8 hour	0.8 hour	0.8 hour	M estimate
XR_i (i = 1,2)	\$11.70/hour	\$11.70/hour	\$11.70/hour	AFLC Standard Cost Factor
(i = 3)	\$12.44/hour	\$12.44/hour	\$12.44/hour	AFLC Standard Cost Factor
XTBF	180 hours	152 hours	110 hours	R MTBF estimate with K-factor = 5
XKK_i (i = 1)	0%	0%	0%	M estimate
(i = 2)	10%	20%	20%	M estimate
(i = 3)	60%	20%	20%	M estimate
$CMARA_i$ (i = 1)	0	0	0	Engineering Estimate
(i = 2)	\$1,000	\$500	\$500	Engineering Estimate
(i = 3)	\$50	\$70	\$70	Engineering Estimate
CAMD	\$2.81	\$2.81	\$2.81	AFLC Standard Cost Factor
WASID	2.0 pounds	1.0 pound	1.0 pound	Engineering Estimate
ANMID	2,000 miles	2,000 miles	2,000 miles	USAF Estimate
$OTPY_j$, PMI_j, $PMMH_j$, $PMLR_j$, m, CMP_i, $WASIDP_j$, $CPPPI_j$, nn,	All values are zero because of maintenance concept; i.e., no preventative maintenance.			M estimate
XK7	1%	1%	1%	Attrition rate assumption based on engineering judgment

Parameter	Value for Strike-Centralized	Shrike-Hybrid	Strike-DP/M	Source
XHCEM	2.0 hours	2.0 hours	2.0 hours	M estimate
EDC	1.0	1.0	1.0	Operational scenario
EOL	10 years	10 years	10 years	USAF
CEPOH	$0.00001/energy unit	$0.00001/energy unit	$0.00001/energy unit	Valve chosen so as not to affect sensitivities
CLIM	$104.20/line item	$104.20/line item	$104.20/line item	AFLC standard cost factor
XMSTSX	4	4	4	M concept (3 intermediate, 1 depot site)
CLSFSA	$20.20/line item	$20.20/line item	$20.20/line item	AFLC standard cost factor
FSPSA	20 sq. ft.	20 sq. ft.	20 sq. ft.	M estimate
CAFS	$9/sq. ft.	$9/sq. ft.	$9/sq. ft.	Engineering estimate
XNMTB	18 students	18 students	18 students	Training estimate
XNMTD	9 students	9 students	9 students	Training estimate
XATB	0.33	0.33	0.33	AFLC standard cost factor
XATD	0.15	0.15	0.15	AFLC standard cost factor
CRTCB	$5,000/student	$5,000/student	$5,000/student	AFLC standard cost factor
CRTCD	$2,500/student	$2,500/student	$2,500/student	AFLC standard cost factor (judged down)
CPPTDM	$200/page	$200/page	$200/page	AFLC standard cost factor
K8	10%	10%	10%	M estimate
CNP_i	50, 95, 140, 185, 230, 275, 325, 365, 410, 455 (2)	50, 95, 140, 185, 230, 275, 325, 365, 440, 455 (2)	50, 95, 140, 185, 230, 275, 325, 365, 410, 455 (2)	USAF estimate
	272, 539, 528, 517, 506, 495, 485, 475, 465, 455 (3)	272, 539, 528, 517, 506, 495, 475, 465, 455 (3)	272, 539, 528, 517, 506, 495, 485, 475, 465, 455 (3)	USAF estimate
CSWM	$212,619/year	$212,619/year	$212,619/year	Engineering estimate

Parameter	Value for Strike-Centralized	Strike-Hybrid	Strike-DP/M	Source
	EW-Centralized	EW-Hybrid	EW-DP-M	
XTBM	159 hours	154 hours	101 hours	Same as strike case
XTBF	199 hours	193 hours	126 hours	Same as strike case
	Recce-Centralized	Recce-Hybrid	Recce-DP/M	
XTBM	159 hours	140 hours	93 hours	Same as strike case
XTBF	199 hours	175 hours	117 hours	Same as strike case

NOTES:
(1) Engineering, Logistics, Training, M, R, Technical Publications, etc., refer to Texas Instruments estimates.
(2) Based on procurement of 550 systems at the rate of 55/year, 10 years.
(3) Based on procurement of 550 systems at the rate of 275/year, 2 years.

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